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CHEMISTRY

OF

NATURE,

DESIGNED AS

A POPULAR EXPOSITION

OF

THE CHEMICAL CONSTITUTION AND RELATIONS OF NATURAL
OBJECTS, AND AS A GENERAL INTRODUCTION TO
THE STUDY OF CHEMICAL SCIENCE.

BY HUGO REEVE.

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PREFACE.

WHILE the science of Chemistry is remarkable for its numerous applications in improving and extending those arts which supply the wants of civilized life, it is not less interesting from the light which it throws on the properties of the natural objects around us, and on those great operations going on at the surface of the earth by which the general system of nature is sustained. The latter very attractive department of chemical science forms the subject of the present volume, which is intended to present in a popular form a view of the composition and chemical properties of those bodies which we find ready-formed by the hand of nature, and an account of the various chemical operations carried on in her great laboratory.

This Work is not designed to convey instructions for performing experiments, but as a book *to be read* by those who may desire some general knowledge of the nature of chemical phenomena, the method of chemical research, and the manner in which chemical experiments are commonly made,—and who may

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of the several kinds of evidence on which the truths of science rest. These all differ, both in degree and kind, from moral evidence and from each other. The evidence of the truths of chemistry is quite distinct from the demonstrative character of the proofs in mechanics; both differ much in nature from the grounds of belief in physiological doctrines; and all are decidedly unlike the peculiar evidence on which the science of geology is reared. For sharpening and invigorating the intellectual powers there is no exercise like the analysis of evidence; and the more varied the subjects of exercise, the better. Men would be much better qualified for the business of life and for the exercise of the liberal professions were they carried through a preliminary course of discipline in the various sciences; and the sciences are now far enough advanced, and their principles sufficiently settled, to admit of their being applied to this end.

It is only of late that the idea of introducing science in general education has been entertained in this country, but it is satisfactory to observe that it is now daily making converts, and that scientific instruction is beginning to be adopted as an essential part of the course in elementary schools. In many private academies the system has been permanently established and is attended with great success. The new High School of Liverpool includes a "Philosophical Department," and in the High School of

Glasgow,* a Chemical Class has been instituted. No doubt, in course of time the Universities will introduce

* It may not be out of place to insert here the prospectus of the chemical class in the High School of Glasgow, which the writer of these pages published on opening the class last winter.

"The Course will be adapted for boys from seven to fourteen years of age. It will consist of a SERIES OF EXPERIMENTS, DEMONSTRATIONS and EXPLANATIONS by the teacher—and FREQUENT EXAMINATIONS. The experiments will be of an elementary character, and the lessons will be illustrated by diagrams, and specimens of natural productions and manufactured substances.

"In conducting this Course, the following objects will be kept in view :—

"1. To familiarize the Pupils with the appearances of the various products of nature and art, apparatus, and philosophical instruments, and teach them how to distinguish them from each other.

"2. To teach them the composition of bodies, their properties, the phenomena arising from their mutual action, their uses, and how and where procured.

"3. To instruct them in the principles on which the Chemical Arts depend, and, by making the first encounter of the study when the mind is pliant and flexible, easily takes up new ideas, and is in the habit of learning—to smooth the way for future advances, and lay such a foundation as shall enable them easily to resume and master the study afterwards, should their taste or profession lead them to it again.

"4. By directing attention to the interesting phenomena of nature and art, and the truths of science, to implant early a taste for and furnish the means of—agreeable, harmless, and rational occupation for leisure-hours in after-life.

"5. To communicate that information regarding the nature of the various bodies and powers which surround us on all sides, and are continually acting on us, and influencing our condition (as Air, Water, Attraction, Heat, &c.), which is now necessary to qualify for general intercourse in society, as science is becoming daily more and more mixed up with the ordinary affairs of life.

"6. To communicate that information—that sense of the importance of the applications of science, which will enable those who

all the sciences into the curriculum for their degree of Master of Arts (their course of general education), and render it worthy of the present advanced state of knowledge.

EDINBURGH, *September 12, 1837.*

will be our future magistrates and councillors, directors of public trusts, merchants, and manufacturers, to appreciate and assist in forwarding those improvements which the advance of science is daily suggesting.

“7. To eradicate prejudices and wrong notions of things (or rather pre-occupy the mind with right notions), and thus crush many childish errors, or save much time in undoing them.

“The striking nature of the phenomena which Chemistry presents—the hidden properties which it discloses—its applications in explaining the great phenomena of nature, and the interesting processes of art, admirably adapt it to excite the interest of the young, and give them a pleasure in learning—to call their mental powers into action—stimulate and give a right turn to that disposition to observe and inquire which is so characteristic of boys—train them to habits of observing accurately—prevent that too great confidence in their preconceived notions, which they are apt to entertain, and lead them to penetrate beneath the surface of things, and reflect upon the causes of what comes before them.”

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CHEMISTRY OF NATURE.

INTRODUCTION,

EXHIBITING A GENERAL VIEW OF THE NATURE OF CHEMICAL PHENOMENA.

1. WHEN we consider our condition in this world, we perceive that we do not contain within ourselves all the elements necessary for the support of life, but are dependent on the various bodies around us for the means of existence. Also, while we cannot maintain life without holding frequent intercourse with the external world, we do not find the substances we require ready made to our hand. All the necessities of life, and all its comforts and luxuries, are derived from objects only the raw material of which is furnished by nature, while all our various operations consist in working this raw material into the condition which fits it for our use.

2. But we are dependent for our existence not only on *our own* operations ; nature herself is continually carrying on a vast number of processes, the

object of which is to adapt the bodies around us to our use. By chemical processes the salt water of the ocean is turned into fresh water, and supplied to us by rivers, springs, lakes, &c. By other chemical operations, the hardest rocks are worn down to the state of earth, and gradually converted into fruitful soils for the rearing of vegetables. By the singular effects which heat is continually producing on air and on water, the temperature of the globe is equalized at different places and different seasons, the extremes of heat and cold are moderated, and thus almost every situation rendered fit for the habitation of man.

3. Depending for existence on the various bodies around us, it is natural to desire some knowledge of their nature and properties ; seeing that the most of them must undergo considerable changes before they are fit for supplying our wants, there are few who will not have a wish to know in what manner these changes, as effected by nature or art, are brought about, —to know by what means sand and sea-weeds are turned into glass ; in what way, and on what principles, vinegar is extracted from wood, —fragrant hartshorn from putrid animal matters, —intoxicating spirit from grain, —how brittle stony matters are converted into *metals*, so useful from their strength and toughness, —how fresh water is supplied to us from the salt water of the ocean, —in what way that extraordinary substance, the air, contributes to preserve our existence, —what is its composition, and what changes it undergoes ; how, when the principle of life is extinct, animals and vegetables decay and disappear, leaving hardly a trace of their former existence.

OPERATIONS OF NATURE AND ART CONSIST IN
CHANGES.

4. It is evident that the processes by which the various substances necessary for the support of life are rendered fit for this purpose must consist in producing changes of some kind ; and, accordingly, if we look at the operations of nature or art, we see a constant series of *changes* going on in every direction. These changes, however familiar we may be with some of them, from witnessing them frequently, are very wonderful indeed, whether we consider the manner in which they are brought about, or the important effects to which they lead.

5. The globe on which we live is constantly moving round the sun, causing the change in the length of the day and the revolutions of the seasons ; and it is continually revolving on its axis, causing the change from night to day, from darkness to light. The moon is constantly changing its position with regard to the earth, and causing changes in the state of the waters or tides. The weather or state of the atmosphere is constantly changing. Sometimes there is a deep blue sky, a light unclouded atmosphere, the sun is clear and bright, and there is a gentle breeze which prevents the oppressive effects of his rays. At another time the heat of the sun is oppressive, and we feel languid under its influence ; the refreshing green of our meadows is changed to a brown, the pastures are burned up, the rivers and streams are dried up, rain does not fall to refresh the soil, the wells and springs refuse their usual supplies of water, and vegetation languishes for moisture. Soon, however, there is a change : all nature

is revived by refreshing showers, the earth again supplies the green blade to our flocks, the crops spring up under the reanimating influence of moisture, and the rivers and streams resume their usual course. At other times the aspect of nature undergoes other changes; the sky is dark and clouded, the clouds discharge their rain in torrents upon the earth, the rivers and lakes become swollen, and floods are poured down upon our cities and fields. At other seasons these waters, which can produce such terrific effects by their moving power, are fast bound in the form of ice; man walks with safety on the surface of rivers and lakes; and the vapour in the atmosphere, instead of being condensed into limpid drops of rain, becomes crystallized and descends in the form of flakes of snow. The changes which water undergoes are, indeed, remarkable; at one time it is found in beautiful feathery crystals; at another time hard, dense, and tough, in the form of ice, capable of being cut and hewn like stones (in the Polar regions houses are built of ice); at another time we find water in the form of a thin colourless vapour, remaining so, however, only for a time, and again changing its condition to that of bubbles or vesicles floating in the air, as in the clouds, or to that of a clear colourless liquid; and sometimes we find it in union with opaque hard solids, as plaster of Paris, itself opaque and hard, having lost all the characters by which we would recognise it as water. In the solid earth itself changes are continually occurring. Rocks and mountains are gradually worn down by the action of air and water, assisted by the vegetable creation; new hills are upheaved by the force of volcanic fire; the ocean is encroaching here;

there the land is becoming slowly elevated ; and, wherever we turn, science will teach us that the principle of change is in continual operation, though it may be ages before a palpable effect is produced.

6. Again, in all our artificial operations there is some change going on. When we perform the simple act of placing a piece of coal on a fire, we do so with the expectation of a succession of changes. The coal diminishes in bulk and is reduced to ashes, a great quantity of smoke and various gases are evolved, light is produced, and much heat is given out. When a lump of sugar is placed in water, we expect that it will undergo a change from the solid to the liquid condition, and that it will cause a change of properties in the water in which it has been dissolved.

7. Now, however different from each other the numerous changes going on may appear, it will be found that there are resemblances between some of them, and differences between these and others, by means of which we can arrange them in separate divisions, those in each division being like each other, and those in separate divisions being unlike, —*i. e.* classify them.

DIFFERENT KINDS OF CHANGES.

8. Sometimes there is a change in POSITION only, as when rain falls from the clouds, or when water is raised by a pump ; sometimes the change takes place in the SHAPE, as when the pebbles on the seashore are rounded by rubbing against each other, or when a log of wood is split by a wedge, or fashioned by tools into a chair or a table ; under this class we may include also such a change as that which is

effected on cotton, when it is made to pass from the state of loose fibres, as got from the seed, to that of a stout thread. The change may be from MOTION to REST, from REST to MOTION, or in the RATE OF MOTION. There are yet more remarkable changes, as in the DISTANCE AND COHESION OF THE PARTICLES of the substance: of this we have an example when water passes into the state of ice or that of vapour; or when a solid body or a vapour passes into the liquid state, as when iron melts by heat, when salt melts in water, or when the vapour in the air is turned into rain or dew. All the substances in nature are found in one of these three conditions; SOLID, like marble or iron; LIQUID, like water or oil; or GASEOUS, like steam, or the air which we breathe; and bodies are frequently changing from one of these conditions to the other. Heat also effects changes on bodies as regards their hardness, softness, brittleness, toughness, &c.; another example of change in the arrangement of the particles, as shown in the tempering of steel. Sometimes the leading change effected is in the COLOUR of the substance, as in dyeing and bleaching. Sometimes the change consists in HEAT, LIGHT, or ELECTRICITY, being produced.

9. Lastly, it happens frequently that there is a striking change in PROPERTIES; the qualities of the substance are no longer the same as before. For example, oil and soda can be converted into soap, a substance with properties very different from either, and applicable to a purpose for which neither separately would answer; and the nature and properties of soap are said to be different from those of oil or soda. Sand and soda, two opaque bodies, two *bodies the particles of which do not adhere firmly*

to each other, and which would be apt to crumble down, which could not be wrought at will into various shapes, and of which one (soda) is readily dissolved by water and other liquids; these can be converted into glass, which is not opaque, but clear, colourless, and transparent, which has strength to keep its particles in union together, which is dissolved only by one known liquid (a scarce one), and which can be rendered soft and flexible, and fashioned into any form we may desire. These last are **CHEMICAL CHANGES**.

10. Such are examples of the kinds of changes in which the various processes of nature or art consist: there are principally two kinds, to which they may all be referred; one of these kinds of changes belongs to the province of **MECHANICAL PHILOSOPHY** (Natural Philosophy), and another to **CHEMISTRY**.

DIFFERENCE BETWEEN CHEMICAL AND MECHANICAL CHANGES.

11. Those changes which involve *visible motion*, or *motion of an invisible influence* (or undulation) *through a sensible distance*, may be included under Mechanical Philosophy. In these there is some force exerted, tending to produce *a distinct motion* (change of position) of a material substance, *i. e.* a motion from one situation to another (as when a heavy body falls to the ground, or a light body, as smoke or a balloon, ascends); or, there is a *motion of some influence or principle from one body to another, over a sensible space* (as in the case of heat or light); or *a motion of some principle along a single body, from one part of it to another* (as in the case of heat, electricity); or, an undulatory motion communicated and transmitted over a sen-

sible distance. In all the operations of Mechanical Philosophy there is motion over an apparent distance,—and *Time* also, in most cases, is an element in the calculation. Also, the nature of the body remains unaltered, being easily made to undergo the like change again.

12. In the changes which Chemistry investigates, on the other hand, the nature and properties of the bodies are quite altered (as when sand and soda are turned into glass, or oils and soda into soap); the actions take place only between the minute particles of bodies; and these must be brought into the closest possible contact before any chemical change can be effected; and, although there is a *transfer* of elementary particles, there is no sensible or apparent motion,—that is, *no motion through any sensible distance*; for this transfer does not take place unless the particles be in close contact, and, the *chemical* action being then completed (whether it be a union or a separation of particles), any motion of the separated or united particles—such as the escape of a gas or the subsidence of a powder—is a mechanical change of position, arising from new relations in the specific weights of the bodies caused by the chemical change.

13. When a heavy body is raised by a lever, when a stone is raised by a cord and pulleys, or a piece of wood split by a wedge, the nature of the substance operated on still remains the same; its position or shape only is altered. These then are mechanical actions. The wedge is a mechanical instrument or power for facilitating labour.

14. But, when wood is exposed to a strong heat in an iron vessel almost closed, it is converted into charcoal, tar, vinegar, and a quantity of gases.

Here there is no change in the position or form of the mass of wood, for the charcoal which remains *is in the same situation and of the same shape, and nearly of the same size, as the piece of wood we used*; but it is much lighter, for a great many of its particles have left it, to be turned into tar or vinegar; it is now black, whereas before it was of a whitish yellow colour; it is now brittle, whereas before it was tough and could not be easily broken; if set fire to now, it will not burn with a bright yellow flame, as it would have done formerly, but with a dull red light.

15. This, then, is a striking example of the difference between chemical and mechanical action. When we applied mechanical action by the wedge, we split the wood into pieces differing from the original piece of wood, and from each other, in shape and size only, but exactly the same in structure and composition.

But when the wood was strongly heated, by which a chemical action was induced, the wood was decomposed or divided into several kinds of substance, charcoal, tar, vinegar, and gas; all differing much in their nature and properties from the original piece of wood, and from each other.

16. In burning coal in an open fire, the *formation* of the smoke and ashes out of a piece of solid coal is a chemical action; but the ascent of the smoke in the air—its change of position—is dependent on mechanical principles.

17. When we raise water by means of a pump (let us suppose the water contains iron), the piston and rod are of the same shape and composition during every part of the process, but they have

frequently changed position ; the water is made to change its situation, but it is of the same nature and composition when brought to the surface, as when ten or twenty feet under ground ;—above, it contains the iron as well as below. But let us apply heat, and distil the water ; we then separate the particles of pure water from the particles of iron with which they are associated—the water rises in vapour, the iron remains behind. Now, raising the water by the pump is a *mechanical process or change* ; separating the iron from its union with the pure water is a *chemical process or change*. And here, also, while the loosening of the attachment between the water and the iron is a chemical change, the ascent of the vapour from the liquid is a mechanical change.

18. Mechanical Philosophy has to do with the construction of the pump, its height and width, the situation and direction of the valves, the form of the handle by which it is worked, and so on. Chemistry would point out the composition of the water, show that it is a compound body, that it consists mainly of two simple bodies, oxygen and hydrogen, but that it also contains other matters, to which it owes peculiar qualities, as hardness—point out the means of detecting these matters, and suggest remedies for the inconveniences which their presence may occasion.

19. Mechanical action, then, is attended with apparent motion or change of position. Chemical action is not necessarily accompanied with apparent motion, but is attended by a change in the properties of the substance operated on, as exemplified above in the manufacture of soap and glass, and in

the action of heat on wood, and on water containing iron in solution.'

ALL THE SUBSTANCES IN NATURE MADE UP OF
FEW MATERIALS.

20. When we look abroad on the world around us, one of the first things that strikes us is the variety in the objects that present themselves to our notice. The endless variety of forms and appearances which animals, vegetables, and other kinds of bodies present, would seem to render it almost a hopeless task to acquire a knowledge of the different substances of which they are composed ; but it fortunately happens, that all the diversified works of nature, and the products obtained from these by art, are made up of a few simple materials ; that we do not need, in studying every different air or liquid, every kind of rock or mineral, every different kind of animal or vegetable, to learn the properties of a new and different substance for each. There are many thousand kinds of stones or minerals, and other inanimate substances ; there is no end to the variety of animals ; there are 80,000 different kinds of plants known ; but, however different they may be from each other in structure or appearance, they are made up of *combinations*, as they are called, of a few simple substances, not above 54 in number, of which chemistry has discovered this endless variety to be composed. Even the same substance can assume many different forms. To select one of the many examples which there are of this :—the diamond, the rarest, the hardest, most transparent and most resplendent mineral known, consists of exactly the same material as the dull, opaque, black, earthy substance called

charcoal. When burnt, it produces the same matter as when charcoal is burnt; and both produce the same substance, namely, *steel*, when they are made to unite with iron.

21. To take yet another example of the great variety of substances with very different properties which may be made from a few materials, let us look at the compounds of two gases, oxygen and nitrogen. These two thin, transparent, and invisible bodies, united in certain proportions, constitute the air which we breathe and are perpetually in contact with, upon which our existence depends, and of which we take in a supply about a thousand times every hour. The same materials, in different proportions, form the intoxicating gas, which produces such peculiar effects when inspired. The same ingredients, in other proportions, form a curious gas, transparent and colourless, which, whenever it meets the air, also transparent and colourless, becomes of a dark red colour, by depriving the air of that part of it which we use in breathing. The beautiful red fumes thus formed are composed of the same two gases. Lastly, the same substances, with a little water added, are the ingredients of *aqua fortis*, one of the most virulent and corrosive poisons known, which instantly corrodes the skin, and produces a deep ulcer when applied to it, and would cause the most excruciating torture and certain death if it could be taken internally. By subjecting atmospheric air to the influence of *electricity*, it has actually been converted into aqua fortis. Let us pause for a moment to reflect on the wonders which a knowledge of nature unfolds to us. Electricity is constantly present in the earth and atmosphere, and it can convert the

atmosphere into a deadly poison. Here then we are surrounded on all sides by the elements of destruction. Yet this substance, the air, and this singular agent, electricity, which, by a slight change in their mutual relations, might destroy us in an instant, are constantly, and in a thousand ways, contributing to our support and our well-being.

SIMPLE AND COMPOUND BODIES.

22. All the different substances of which we have any knowledge, whether formed by the hand of nature or processes of art, may be arranged in two divisions, 1. *Simple bodies*, called also *elementary bodies*, or *elements*; and 2. *Compound bodies*, or *compounds*.

23. The well-known metal, LEAD, is a *simple body* or element, that is,—so far as we know, it consists of only *one* kind of substance—lead; we cannot extract from it any substance of a nature different from itself (*i. e.* it cannot be decomposed); we cannot alter it or transform it into any matters different from lead, except by *adding some different kind of matter to it*; we can diminish it in quantity only by taking lead from it, when lead alone will remain; and, we cannot form it by uniting together any known substances.

24. RED LEAD, a well-known paint, is a *compound*. It consists of *two* bodies which differ very much from red lead and from each other, namely, *lead* and *oxygen*; either of these substances can be extracted from it, when the remainder will no longer be red lead; a quantity of red lead may be entirely resolved (or transformed) into these two bodies (*it can be decomposed*); and red lead can be

formed by bringing these two bodies in contact, and causing them to unite with each other.

25. Charcoal, phosphorus, sulphur, iron, copper, silver, and about fifty others (see Table, par. 65), are simple, like lead, each consisting (so far as we know at present) of only one kind of substance. Iron contains nothing but iron. We can never get any different substance out of it, and it is called *simple*, in opposition to such a body as steel, which contains both iron and charcoal, two different substances, and which, from consisting of more than one kind of matter, is called *compound*. The iron and charcoal are said to be chemically united.

NATURE OF A CHEMICAL UNION.

26. But when we examine a bit of steel, we cannot perceive any traces of the charcoal, far less can we take out the bits of charcoal from the steel and leave the iron behind. And this brings us to the nature of chemistry. If we take a few iron filings, mix them with some clay in powder, work them up with a little oil into a ball, and allow the ball to become hard and dry; upon looking at the ball thus made, or at a fractured surface of it, we shall be able to see the particles of iron by themselves, and the particles of clay by themselves, and we could pick out the particles of iron and separate them from the clay. But not even by the most powerful microscope can the particles of iron and charcoal be discovered in the steel. They are there united, or, to use the chemical term, *combined*, in such a way that the two different substances, the iron and the charcoal, appear to be but one kind of substance. This, then, is an example of what chemistry effects; it

causes two different substances (whether simple or compound) to unite, firmly adhere to each other, and form a third substance, which apparently consists of only one kind of material. A familiar example of chemical union presents itself in dissolving any solid in a liquid, as sugar or salt in water. The solid disappears—we lose sight of it;—the two together appear but as one substance: they are chemically combined. Such is the grand characteristic of chemical unions. Soap consists of oil and soda, yet, when we examine a piece of soap, we cannot see the oil or the soda; we see what appears to be *one* substance. This combination of oil and soda is a chemical action, and the manufacture of soap a chemical process. In the same way the water of many wells and springs, as hard water, is combined with lime; but we do not see two substances—the lime disappears, and the water and the lime together appear as one substance: they are chemically united. Let a little rosin be reduced to a fine powder; it will then appear of a white colour. Shake it with a little spirit of wine in a glass, the rosin will entirely disappear (be dissolved), and the liquid will acquire a light brown colour,—another example of a chemical union.

CHEMICAL ATTRACTION.

27. Why did the rosin, as mentioned in the last paragraph, disappear when shaken along with the spirit of wine? Why did it not remain a white powder, and why did the liquid acquire a brown colour? There must be some power or influence operating to draw these bodies into such intimate union with each other. To express this power, we

use the terms *chemical attraction*, or *affinity*, these two terms being synonymous. We know not how this power operates, we know not its nature, we can only judge of it from its effects; but we see that it is the nature of these substances to be united in this way when they are brought together; also, we see that a great number of other substances have a disposition to unite in a similar manner; hence we infer that there is some peculiar influence acting between substances which disposes them to unite with each other, and as they appear to be attracted or drawn towards each other, it is called *attraction*, and receives the epithet, "*chemical*," to distinguish it from other kinds of attraction.

28. By combination (chemical union) two different bodies unite and form a third, differing very much from either. It is chemical attraction which causes them to combine when brought together, and thus this agent is the cause of the *differences* which we find in bodies. Were there no such agent as chemical attraction, there would be only about 54 different kinds of substances, the simple bodies (23), and of these several are very rare; but chemical attraction makes these unite with each other, and these compounds (24) unite with the simple substances and with each other, so that there is almost no end to the number of different bodies brought into existence. It draws towards each other the particles of *different* kinds of matter, and binds them together, causes them when they are brought into contact to enter into new arrangements and combinations, and thus gives rise to the variety in the objects around us, and to the varied phenomena of *chemistry*. Oxygen, a light aerial body, and lead,

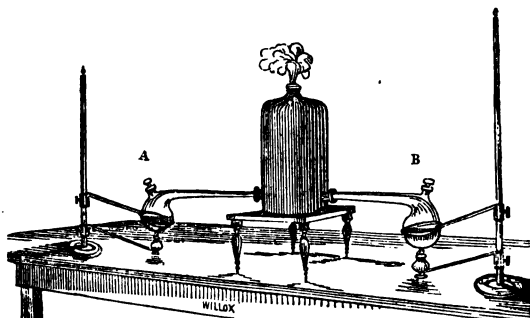
heavy, solid, and a metal, are widely different from each other, and would never produce any other kind of matter, were there no such power as chemical attraction ; but this power can cause them to unite and thus produce red lead, an earthy powder, very different from either in every respect. By the effects of this chemical attraction, then, a few simple materials give rise to the diversified works of nature and of art.

CHANGE OF PROPERTIES ATTENDS CHEMICAL
COMBINATIONS.

29. When two substances combine chemically, there is generally a change of *properties* accompanying the combination: the compound produced has properties materially different from those of the substances which compose it. We had an example of this in the case of glass (9), which has properties so extremely different from the substances of which it is made. Aquafortis, the corrosive poison mentioned in paragraph 21, which cannot be touched with impunity, has an attraction for potash, a substance also of a very caustic and corrosive nature. When they combine, a substance is produced which may safely be tasted, as it has little or none of the acrid qualities belonging to each: this compound is nitre or saltpetre. Here the substances in the combined state have entirely lost those qualities by which they are distinguished when separate. That mild and harmless substance, common salt, is composed of a singular metal, which takes fire whenever it meets with water, and a green coloured gas or air, chlorine, which is an extremely pungent and acrid substance ; so great is the change of properties when these two

substances, by uniting chemically, form common salt. Sometimes new and very marked properties are acquired by chemical union, where the combining substances had no very striking properties, or none resembling those which they have when united. That mild and tasteless substance, sulphur, by uniting chemically with oxygen, a gas not possessed of any acrid properties, produces sulphuric acid, the most powerful of the acids, and one of the most acrid and corrosive substances known.

30. The following experiment will present a striking view of several of the effects of chemical combination.



Into the glass vessel A, pour a little marine acid, and into the vessel B, a little ammonia (hartshorn), and apply heat at the bottom of each of these vessels by a spirit lamp. By the heat, the two liquids will be turned into vapours, and the opening in the top of each vessel being closed by its stopper, the vapours will come along the tubes and meet in the glass vessel in the middle. In the vessel at each side and in the tubes leading from them to the large vessel,

both vapours are quite transparent and invisible; but they have a chemical attraction for each other, and they will unite whenever they meet: accordingly, when they enter the large vessel and come in contact with each other, the point where they meet is marked by the formation of a greyish smoke or vapour, which gradually increases with a sort of turbulent motion as more of the vapours enter, at last fills the whole of the vessel, and is expelled like smoke from a chimney by the opening at the top. This grey vapour soon becomes condensed into a white powder, of which part is carried out along with the vapour at the top, and the greater part falls down in specks on the sides and bottom of the vessel, the bottom soon becoming entirely covered. A curious spectacle is presented by this experiment: while the vessel in which the vapours meet soon becomes quite opaque, and while this tumultuous action is going on inside, the tubes conveying the vapours remain clear and colourless, the vapours passing through them in the most peaceful manner to the scene of action, where they are to meet each other, be transformed by the encounter, lose their light ethereal form, and fall down a dull earthy powder. The vapours are compelled by the laws of nature to leave the liquid when heat is applied, and they are equally under the necessity of combining when they meet, giving up the gaseous form, and forming a white powder: whenever they come in contact, they must obey that law of nature which has been called chemical attraction.

31. Now, the marine acid is an acrid poison; at natural temperatures it emits vapours which are extremely irritating to the eyes, lungs, and nostrils;

and it turns a blue infusion of cabbages to a red colour:—ammonia or hartshorn is of a caustic nature, and emits very pungent vapours, as every one knows; and it turns blue vegetable colours to a green. We may enumerate, among others, six remarkable changes which have been effected upon these substances by combining chemically.

(1.) From being gaseous or aerial, they have become solid. This involves also a change in bulk; they occupy much less space.

(2.) From being transparent and colourless, they have become white and opaque; visible, from being invisible.

(3.) The white powder does not, at natural temperatures, emit copious vapours.

(4.) The acrid and caustic qualities are lost or destroyed: the white powder is comparatively mild.

(5.) The white powder cannot affect the vegetable colours as either of the liquids does; it produces no change of colour.

(6.) The white powder* differs from the marine acid, and from the ammonia, in the manner in which it is affected by other substances; and hence it is fit for a number of purposes for which they would be totally inapplicable, and is totally unfit for any of the uses to which they are applied.

The above example will convey some idea of the effects produced by one kind of chemical action—namely, chemical combination.

CHEMICAL DECOMPOSITION.

There is yet another chemical action to be ex-

* Sal-ammoniac, or muriate of ammonia.

plained before we can have any adequate idea of the nature of chemistry—*chemical decomposition*.

32. Take the liquid which was formed by dissolving rosin in spirit of wine (26) and pour it into a glass containing common water. Immediately we shall see the liquids turn white and opaque, from a powdery substance being formed and diffused through them. It will be found that we have recovered from the liquid the powdered rosin which we dissolved in the spirit of wine, and that the liquid has no longer a light brown colour. How has the rosin recovered its solid form? How has it been detached from the spirit of wine which kept it in the liquid state in consequence of the chemical attraction existing between them?

33. It would appear from this experiment, and others of a similar kind, that all bodies have not the same degree of chemical attraction for each other; some have a very great attraction for each other, and between others there is very little attraction. In the above example there were three different substances used, rosin, spirit of wine, and water. Between rosin and spirit of wine there is a strong chemical attraction, and they readily unite; between water and spirit of wine there is also a strong chemical attraction. But the spirit of wine has a *stronger* attraction for the water than for the rosin; consequently, when a compound of spirit of wine and rosin is brought into contact with water, the spirit of wine, preferring the water to the rosin, will leave the rosin and unite with the water—will give up its chemical connexion with the rosin, and enter into chemical union with the water. But the rosin, when

minutely divided, and by itself,* is a white powder; whenever, then, it is thrown off by the spirit of wine, it, of course, assumes this form, and hence the appearance of the white powder when the two liquids are mixed.

34. Such is an example of chemical decomposition. Without entering particularly into any varieties of this kind of action, its general nature may be stated in the following terms.

If, of three bodies, A, B, and C, B has a greater chemical attraction for C than for A; if A and B be in chemical union with each other; and if C be brought into contact with

A	A
B	
the compound,	B will leave A, and
enter into chemical combination with	C
C.	B C

The subjoined arrangement of the letters will convey a better idea of this, the letters within the brackets representing the substances which are chemically united. At the left they are shown as they are before the decomposition has taken place; at the right in the state in which they exist after decomposition.

35. This process of decomposition, or the separation of two substances chemically combined, is a very interesting and very important chemical operation. By decomposition, spirit of salt, an acrid, poisonous acid, is extracted from these wholesome substances, water and common salt; it is by decomposition that aquafortis is separated from potash, with which it is united in nitre; it is by decomposition that ammonia or hartshorn is separated from spirit of salt, with

* By this is meant that it is not in chemical union with any substance, not that it is in a separate vessel.

which it is combined in sal-ammoniac ; it is by decomposition that wood or coals, when they are burnt, are separated into a light, transparent, invisible gas, which flies away, and the grey or white ashes which remain ; it is by decomposition that dead vegetables are separated into a light airy matter, and a black powder or charcoal, which remains in the soil, and gives the very dark or black appearance to soils which contain much peat or turf ; and it is the decomposition of such dead vegetables that, in a manner, grinds them down, so as to be in a fit state for affording nutriment to new generations of plants. This separation of substances which are combined, either by bringing in contact with them a substance which has a very great attraction for one of them—or sometimes by simply heating them—frequently occurs in chemical changes, is taken advantage of in a thousand different ways in the arts and manufactures ; and is the leading feature in many natural processes going on at the surface of the globe.

36. All these, then, are examples of chemical actions. They give an idea of the kinds of actions or changes which chemistry describes, and of the means by which its effects are produced. It will be seen that the grand agent in bringing about all these changes, is *chemical attraction* ; and that the operation of this power gives rise to two kinds of action, combination and decomposition : in these two changes almost all chemistry consists. *When it is understood that there are different kinds of substances on the earth, that these different bodies have a disposition to unite with each other and form new varieties, and that they have not all an equally strong attraction for each other, but that one sub-*

stance will sometimes leave a body with which it is united, and unite with another in preference; when these facts are borne in mind, we have a clue to the whole phenomena of chemistry.

DERIVATION OF THE TERM "CHEMISTRY."

37. The derivation of the word "chemistry" is not known with certainty. According to Dr Thomson, the word first occurs in the dictionary of a Greek writer, Suidas, who lived in the eleventh century, and who defined chemistry to be "the preparation of silver and gold." Chemistry is the English form of the word: in Greek it is *χημεία* (*chemeia*). The word is also said to occur in a manuscript written in the fifth century, called "A faithful description of the sacred and divine art of making gold and silver," in which the art receives the name *χημεία*. This Greek word is supposed to be derived from *χύνω*, "I melt," as melting of solids was a frequent operation of the chemists; or from *Chemi*, a name given to Egypt, where the imaginary art of making gold and silver was believed to have arisen. Dr Young was of opinion that the term chemistry, as referring to the secret art of transmutation (converting the common metals into gold or silver), was probably derived from a Coptic word *khems* or *chems*, signifying *dark, obscure*. Others have supposed that it is derived from an Arabic word *kyamon*, meaning "the substance or composition of bodies." It has also been referred to another Arabic word, signifying "fire," or "to burn," the experiments of the alchemists (those who searched for the art of making gold and silver) being performed chiefly by means of fire.

ORIGIN OF THE SCIENCE.

38. Whatever may be the precise origin of the word chemistry, it is certain that at first it signified little more than the imaginary art of transforming the base metals, as lead or copper, into the noble metals, gold and silver, by means of the philosopher's stone. Those who searched after this art were called **ALCHEMISTS**. Some of the alchemists aimed also at the discovery of an *elixir*, or universal remedy, which was expected to cure all diseases, and prolong life indefinitely.* Chemistry owes its existence entirely to the moderns, the ancients being quite unacquainted with it as a science; and, what is singular, the experiments of the alchemists, who may be regarded as a set of fanatics or impostors, laid the foundations of this important division of human knowledge. While performing experiments with the view of making the expected discoveries, a number of chemical phenomena were developed, and the chemical relations of a number of different substances were ascertained. These formed a certain stock of materials, which led the way to fresh discoveries, and thus afforded the basis on which the present stupendous structure of chemical science has been reared. Although a great number of chemical facts were known in the older times, and many chemical phenomena have been occurring daily in all ages and all places, it is chiefly to the facts

* By means of which, in their own words, "the greatest disease is cured, and sorrow, distress, evil, and every hurtful thing evaded; by help of which we pass from darkness to light, from a desert and wilderness to a habitation and home, and from straightness and necessities to a large and ample estate."

brought to light by the experiments of the alchemists that we are indebted for a stock sufficient for the purpose of a generalization, and it is only within the last century that these have been combined into a systematic form, their causes examined, and a science deduced from them.

39. Such was the origin of the science of chemistry, now, *as a science*, so intimately and inseparably interwoven with every thread in the web of civilized life; and which has unfolded to us the nature of so many of those changes by which the system of creation is sustained, and the world adapted for the support of living beings.

CHAPTER I.

INERTIA OF MATTER.—ATTRACTION AND REPULSION.

40. The changes which chemistry describes are owing chiefly to the influence of chemical attraction. But there are other properties of bodies concerned in producing (sometimes in preventing) chemical changes, and to which we must occasionally refer in describing the composition of bodies and the effects produced by their action on each other.

INERTIA.

41. All kinds of matter are in themselves inert and lifeless. They are endowed with what has been called *inertia*, occasionally termed *vis inertiae* (the power of inertia), or more popularly expressed

by some, *stubbornness*. This means that matter is always disposed to remain in the condition in which it may be at the time, whether it be moving or at rest; whether solid, liquid or gaseous; whether simple or compound; that matter is endowed with an unwillingness to change, that it has no power to put itself in motion, of itself to put a stop to any motion which may be communicated to it, or to produce any change upon itself.

42. A ball shot up in the air would move for ever, and continue receding from the earth, if left quite to itself; but there are two causes tending to arrest its progress—the resistance of the air, which opposes it at every step, and the attraction of the earth, which pulls it downwards. The ball would never move from the gun-barrel were force not applied to expel it; and, being once in motion, would never stop but from the action of those forces or causes just mentioned. In the same way the smoke which arises from a fire, if left to itself, would not rise; but it is pushed upwards by the weight of the air, which is heavier, and presses it on every side.

43. To take a chemical illustration of inertia, the coal which we dig from the mine has in itself no disposition to change, and might remain for centuries in the ground unaltered; but the moment that it is exposed to the action of heat, its inertia is overcome, its particles are converted into gases, and thus they are made to assume a form very different from that in which we find them.

44. It is thus a general property of matter, or there is a general disposition in matter not to change its condition, and nevertheless there is a perpetual succession of *changes* going on in every kind of

matter ; there are therefore some causes, influences, or powers that overcome the inertia of matter, and give rise to this infinite variety of changes.

45. There are two grand powers acting upon every kind of matter, ATTRACTION and REPULSION ; these give rise to the diversity of forms and motions which we see.

46. Attraction is that power or force which tends to draw bodies, or the particles of bodies, towards each other, and is of four kinds, *attraction of gravitation, electric attraction, attraction of cohesion, and chemical attraction or affinity.**

ATTRACTION OF GRAVITATION.

47. *The attraction of gravitation, or gravity, is that which acts both between masses and between minute particles of matter, in drawing them towards each other ;—but the peculiar feature of this attraction is, that it is capable of acting though the substances between which it acts be at a distance from each other.* It is a fixed property of all bodies in nature, that they have a tendency to approach to each other, at whatever distances they may be placed. The sun attracts the earth at a distance of 95 millions of miles ; the earth, by its attraction for the moon, at a distance of 240,000 miles, keeps her rolling in her orbit, and prevents her receding from us ; the moon by her attraction for the earth, affects and draws towards her those parts of the earth which are moveable on its surface, as the waters and the atmosphere ;—hence the phenomena of tides. The

* Possibly there may be only one kind of attraction, but it is convenient to speak as if there were different kinds of attraction, though they may only be varieties of one fundamental principle.

earth, by its attraction, prevents bodies from going far from the surface, and this attraction is the cause of bodies falling to the ground. This same attraction is exerted between the various bodies on the surface of the earth. It causes a plummet suspended near a high hill to lean towards the hill; the great mass of matter in the hill draws the plummet towards it: were there no hill present, or were there a similar hill on the other side of the plummet to counteract the effect of the first hill, the plummet would hang quite perpendicular.

48. This attraction, then, *the attraction of gravitation*, acts in drawing different masses of matter towards each other; and it acts on all bodies whatever—between the various bodies placed on the surface of the earth as well as between the sun and the planets, at the distance of hundreds of millions of miles.

ELECTRIC AND MAGNETIC ATTRACTIONS.

49. If a rod of glass or of wax be rubbed briskly with a piece of silk, it will acquire the property of drawing towards it light bodies, such as hairs or feathers: this is *electric attraction*. When a loadstone draws iron filings or a needle towards it, we have an example of *magnetic attraction*. These two kinds are now considered as one.

ATTRACTION OF COHESION.

50. There is another kind of attraction, called the attraction of aggregation, or cohesion. It is easily seen that every kind of matter, as lead, marble, water, consists of a great number of minute particles adhering to each other, so as to form a lump or large

mass. It is this cohesive attraction which keeps these particles in firm union with each other. It is the attraction of gravitation that makes a stone fall to the ground ; but it is the attraction of cohesion that keeps in union with each other the little particles of which the stone is composed. It is this attraction between the particles—this force with which they adhere to each other—which resists our efforts to separate them, and renders it so difficult to break the stone to pieces, for the stone is a mass of small particles bound to each other by cohesion. In the same way, the particles of a piece of lead, glass, marble, or iron, are bound to each other so as to form one mass. This kind of attraction then (called also *attraction of aggregation, contiguous attraction*) acts only between the minute particles of matter, and only when these particles are in contact with, or quite close to each other, at what is called insensible distances ; which means that the particles thus united, if not in contact with each other, are at distances so short as not to be perceptible by our senses.

51. The attraction of gravitation can act between lumps or masses of matter, and though they be at great and perceptible distances from each other.—When a heavy body is suspended by a string or wire, *gravitation* pulls it downwards, makes it hang towards the ground, and tends to break the wire. The *cohesion* between the particles of the wire enables it to support the heavy body.

52. This cohesive attraction, however, is of different degrees of strength in different substances, and in the same substance at different times. In some, the particles adhere to each other with great force, as in gold, silver, iron, marble, and other *solid*

bodies ; in others, the particles have a less adhesive force, and are moveable upon each other, as in oil, water, quicksilver, and other *liquids* ; in others, the cohesive principle appears to be altogether absent, and we have then *aërial bodies* or *gases*, as steam or the air.

53. The cohesive force is of different degrees of strength in the same substance at different times, as is seen in the case of melted lead, between the particles of which there is so little cohesive force that they are liquid and quite moveable on each other, while in the same substance when cooled, the particles are very firmly bound together in the solid form,—also seen in ice, passing into water, and then to steam.

REPULSION.

54. It will be recollected, that there are *two* grand powers acting upon every kind of matter—*attraction* and *repulsion*. Now, the kind of attraction of which we have just been speaking is opposed in its tendency to draw the particles of matter close to each other by this principle—repulsion, which tends to separate them, to repel them from one another ; and, as in the moral world some ancient philosophers supposed that there are two opposing principles, good and evil, constantly contending for superiority ; so, in the physical or material world, it is now demonstrated that there are two antagonist forces continually acting on every kind of matter, the forms of which are determined by the comparative quantities of the opposing principles which may be present. If cohesion were the sole ruling principle, the world would be a dull and inert mass, for the tendency of

cohesion is to draw the particles of bodies into close contact with each other, and preserve them in that state. But the repulsive principle, by driving asunder the particles of bodies, gives rise to numbers of changes and motions, and may thus be said to infuse life and activity into inanimate objects. To illustrate this, it will be sufficient to mention at present that without the power of repulsion, there would be no winds, rain, dew, rivers, streams, or springs. The atmosphere would be motionless; all the water on the globe would be collected in the salt ocean. But repulsion is present in all bodies, and prevents their particles being immovably bound to each other in hard and heavy masses by the attraction of cohesion.

55. This principle, *repulsion*, is generally believed to be the same as *heat*, and its action is well exemplified by the different states in which water exists. When there is a small quantity of heat or repulsive principle present, cohesion acts powerfully, and we have the particles firmly fixed and adhering to each other, forming ice. When heat is added, the repulsive power is increased, the ice melts, the cohesive power is overcome so far, and we have the particles loosened to a certain extent, moving freely upon each other, readily yielding to any impression, constituting the common or *liquid* state of water. When additional heat is supplied, the cohesive attraction is altogether overcome, the particles are driven far asunder by the repulsive principle, which is now predominant, and we obtain water in the state of an æriform body, or vapour, constituting steam, and in which the particles are at such a distance from each other, that they occupy 1700 times the space

which they did when in the liquid form. When the body is cooled (the heat withdrawn from it) it returns successively to its former states.

56. This power of repulsion gives rise, then, to three different forms of matter, the SOLID, LIQUID, and GASEOUS ; and we shall find that this principle is in continual operation in producing chemical changes, as well as chemical attraction. It is now generally believed, that all gaseous bodies might be rendered liquid and then solid, if we could *deprive* them of a sufficient quantity of their repulsive principle—heat,—and that any solid might be turned into a gas or vapour, if we could *communicate* to it a sufficient quantity of the same powerful agent.

57. This action of heat is also seen where there is no change of condition : if a solid or liquid, as iron or water, be heated, its particles will be repelled to a little distance from each other, so that it will occupy a greater space than when cold. When it is cooled again, so much repulsion having left it, cohesion will operate more vigorously, and draw the particles back to their former distances. The same holds true with gases ; if a bladder, tightly closed at the mouth, and containing a quantity of air, but not quite full, be held before a fire for a short time, the air will expand so as to distend the bladder : upon being cooled, it will return to its former flaccid condition. Solids expand in bulk from 1-117th to 1-600th part when heated from the temperature at which water freezes (32° F.) to that at which it boils (212° F.). Liquids expand from 1-9th (spirit of wine) to 1-55th (quicksilver) when heated through the same range. Gases have all the same rate of

expansion, increasing 3-8ths in bulk when heated from the freezing to the boiling point of water.

58. It is thus by increasing the bulk of bodies, or by converting liquids into light vapours, that heat gives rise to motions and various changes, and hence may be called the *moving power* in the operations of nature. There are two chief sources of heat—the sun, and subterraneous heat ; but, except in the case of volcanic action, it is considered that it is chiefly the sun's heat which acts at the surface of the earth, and for about 100 feet under the surface. Below that the effects of the sun's heat are not felt ; and the temperature rises about one degree Fahrenheit for every fifty or sixty feet of descent towards the centre, and is nearly the same at equal depths in every part of the world, and at every season, as ascertained by examination of mines and artesian wells.

CHEMICAL ATTRACTION OR AFFINITY.

59. The three powers or influences which we have seen are constantly acting on every kind of matter, namely, attraction of gravitation, attraction of cohesion, and repulsion, might be exemplified by one kind of matter alone, as water or quicksilver. Attraction of gravitation would cause quicksilver to fall to the ground when poured out of a vessel ; attraction of cohesion would keep the particles fixed to each other when quicksilver is frozen ; or make them collect into globules when any drops of it fall on a table ; and repulsion would drive the particles asunder in the form of vapour when heat is applied.

60. But there are different kinds of matter—there is iron and sulphur, charcoal, phosphorus, gold,

zinc, lead, copper, quicksilver, oxygen, hydrogen, and nearly fifty other kinds of matter, differing in a great many points besides in the quantity of cohesive attraction or repulsion existing between their particles: and this universal agent, attraction, which draws bodies towards each other, and binds firmly together the particles of a piece of lead or copper, also binds together the particles of different kinds of matter. When it does this, it receives the names *chemical attraction*, *attraction of composition*, or *affinity*.

61. The compound, brass, consists of two kinds of matter, copper and zinc. But a lump of brass is made up of a number of small particles similar to each other, united by cohesion. When we break down a bit of brass and reduce it to filings, we overcome the cohesive attraction; but the small particles into which it is divided are brass as well as the lump. The minute particles of brass united by cohesion in a lump are called the *integrant parts or particles*. Each of the integrant particles, however, contains copper and zinc, extremely different from the brass and from each other, *and these cannot be separated by mechanical means, such as pounding or rasping*, which is a characteristic feature of a chemical union. They are united by chemical attraction, and are called the *component or constituent particles or parts*. By their union they form an integrant particle. If a body be simple (23), as copper, its integrant particles will also be simple; but if it be a compound (23), as brass, its integrant particles are also compound. Thus the same particles may at one time be integrant particles, at another, constituent particles. A particle in a mass

of copper is an *integrant* particle of the copper, but united with zinc in brass, it is one of the constituent particles of the brass. From this we will understand better the difference between *mechanical division* and *chemical division* (decomposition). By mechanical division, we merely loosen the bonds by which the *integrant particles* are attached: chemical division separates from each other the *constituent particles*. Sometimes the word *atom* is used instead of particle. Both have the same meaning, expressing the smallest parts of which we imagine bodies to be composed.

62. The following page contains a tabular view of the different kinds of attraction and repulsion:—

ATTRACTION,	Between minute particles only	1. <i>b.</i> COHESION, binds together the minute particles of <i>similar</i> kinds of matter, acting only at insensible distances. 2. <i>c.</i> AFFINITY, binds together the minute particles of <i>different</i> kinds of matter, acting only at insensible distances.	(apparent) distances.	the ground. Preserves the minute particles of a piece of lead in firm union with each other, so that a great force is required to separate them. Converts metallic lead and oxygen gas into a red earthy powder. When lead is melted by heat, its particles are loosened, then moving freely upon each other. When water passes into steam, its particles are at 1700 times their former distances. If a bladder, partly filled with air, be heated, the particles of air will be so far repelled as to distend or even burst the bladder.
REPULSION,	Between minute particles only	Tends to separate the minute particles of similar kinds of matter from each other, being thus directly opposed to Cohesion; hence, as one or other of these powers predominates in different substances, they are found in the solid, liquid, or gaseous condition.—Repulsion is believed to be owing to the influence of Heat, which is present, more or less, in all bodies.	(apparent) distances.	the ground. Preserves the minute particles of a piece of lead in firm union with each other, so that a great force is required to separate them. Converts metallic lead and oxygen gas into a red earthy powder. When lead is melted by heat, its particles are loosened, then moving freely upon each other. When water passes into steam, its particles are at 1700 times their former distances. If a bladder, partly filled with air, be heated, the particles of air will be so far repelled as to distend or even burst the bladder.

CHAPTER II.

ARRANGEMENT TO BE FOLLOWED.—TABLE OF THE
ELEMENTS.

63. There are three classes of bodies which are the objects of chemical inquiry. 1. Those natural compounds which exist ready formed in the world around us. 2. Those compounds which are procured only by artificial processes. 3. The *simple bodies* or *elements* (either found in nature, or extracted from natural compounds by chemical processes) of which all bodies are composed. The nature, properties, and uses of the first class, are the subjects treated of in this work—the CHEMISTRY OF NATURE;—and in describing these, we must describe not only the natural compounds themselves, but the elements of which they are composed.

64. Of the natural compounds every one has some knowledge, however slight; the elements are not so well known. There are many of them that some persons have never even heard of. Now, the most simple and natural way of studying chemistry, is to begin by examining matters with which we are already somewhat familiar, as air and water; to study their properties and relations to other substances to inquire whether they are simple or compound; and if in the latter condition, to separate

their constituent parts (63) from each other, and examine the properties of their elements in the uncombined state; thus proceeding from the *known to the unknown*—in short, to proceed as if we were performing experiments, with the view of discovering the nature of the substance.

65. We shall therefore commence with the compounds as they exist in nature, prefixing, however, for reference, the following table of the ELEMENTS or SIMPLE BODIES. Of these, so far as chemists know at present, all bodies are composed,—none of them can be resolved into any matter different from itself, and all bodies can be reduced to one or more of these. Future discovery may show that some of these are not simple, but compound, or may unite several now supposed to be different. But these 55 are the present elements of the chemist. The first four marked *g*, when detached from other bodies, can only be procured in the gaseous state. Two marked *l*, BROMINE and MERCURY, are liquid at the usual temperature of the atmosphere. All the rest are in the solid state at ordinary temperatures. Those marked *n* are found *native*, *i. e.* they exist in nature in the simple or uncombined state.

Of course, the compounds mentioned in the following table are all natural products.

Those compounds only are mentioned which are very abundant, or in which the element exists in large quantity.

TABLE OF THE ELEMENTS.

I. NOT METALLIC.

Name.	Discovered by	When	Exists in Nature in
OXYGEN, <i>g. n.</i> ...	{ Priestley	1774	Air, water, earths (including sand, stones, earth of every kind, and rocks), and organized bodies,—the most abundant of the elements.
HYDROGEN, <i>g.</i>	{ Scheele	1775	Water, organized bodies, naphtha, petroleum, mineral pitch, asphaltum, jet, common coal, cannel coal, amber, sulphate of ammonia, muriate of ammonia (sal-ammoniac).
NITROGEN, <i>g. n.</i>	Rutherford	1772	Air, animals, some vegetables, as fungi, cruciferae, nitrate of potash (nitre), nitrate of lime, nitrate of soda, common coal, sulphate of ammonia, muriate of ammonia (sal-ammoniac), some hot springs.
CHLORINE, <i>g.</i>	Scheele	1774	Common salt (chloride of sodium), hence in sea-water, salt lakes and springs, rock-salt; sal-ammoniac (muriate of ammonia), horn silver (muriate of silver), muriate of copper, horn quicksilver, and some rare ores of lead, and in small quantity in animal substances, and in sea-weeds.
SULPHUR, <i>n.</i>	Known to the ancients	...	Native, in native sulphuric acid, gypsum, heavy spar, alum, stone, iron pyrites, green vitriol; sulphurets of arsenic (realgar, orpiment), silver, copper, antimony, lead (galena), zinc (blende), quicksilver (cinnabar), bismuth, cobalt; and in small quantities in other minerals of less frequent occurrence,—sparingly in organic bodies.

Name.	Discovered by	When	Exists in Nature in
SELENIUM,	Berzelius.....	1818	Some iron pyrites, and ores of silver, copper, and a few other metals.
BORON,	Davy	1807	Native boric acid, borax (limal), datholite (borate of lime), boracite (borate of magnesia).
PHOSPHORUS	Brandt.....	1669	Animals, chiefly in the bones, wavelite (phosphate of alumina), apatite (phosphate of lime), bog iron ore, some other ores of iron, and in some ores of manganese, uranium, copper, lead.
CARBON, <i>n.</i>	Known to the ancients ...		Native, pure in the diamond, constitutes the greater part of mineral charcoal, plumbago or black lead, jet, every kind of coal, naphtha, petroleum, mineral pitch, asphaltum, amber; in clay-alate; also in limestone, marble, and every carbonate, as of magnesia, of baryta (witherrite), of strontia, of soda (natron); clay iron ore, in some ores of bismuth, silver, copper, lead, zinc (calamine), and abundantly in all organic bodies.
IODINE.....	Courtois.....	1812	Some salt springs, in the water of the Mediterranean, in sponges, some shell-fish, as the oyster, and in sea-weeds.
BROMINE, <i>l.</i>	Balard.....	1826	Sea water, water of the Dead Sea, many saline mineral springs, and sea-weeds containing iodine.
FLUORINE.....			Fluor spar (fluat of lime), and some rare minerals of alumina and cerium.
2. METALLIC.			
POTASSIUM.....	Davy.....	1807	Land vegetables abundantly, sea-weeds, and animals, mica, talc, felspar, chlorite, pumice, obsidian, soapstone, and other ingredients of rocks, nitre, alumsone, and some kinds of soil.

Name.	Discovered by	When		Exists in Nature in	
				Discovered by	When
SODIUM	Davy.....	1807		Sea-weeds, land vegetables and animals, sodalite, albite, pichstone, pumice, obsidian, and other ingredients of igneous rocks, natron, sulphate of soda, nitrate of soda, borax, common salt.	
LITHIUM	Davy.....	1813		Petalite, and a few other rare minerals.	
CALCIUM	Davy.....	1807		Augite, hornblende, felspar, and other ingredients of rocks: slates, clays, earth, carbonate of lime (marble, limestone, &c.), fluor spar, gypsum, apatite, garnet, asbestos, bones and shells of animals, &c.	
BARIUM	Davy.....	1807		Witherite (carbonate of baryta), heavy spar (sulphate of baryta).	
STRONTIUM	Davy.....	1807		Arragonite, strontianite (carbonate of strontia), celestine (sulphate of strontia).	
MAGNESIUM	Bussy.....	1830		Augite, hornblende, asbestos, talc, soapstone, chlorite, bitterspar, magnesite, limestone, some clays, mica, carbonate of magnesia, sulphate of magnesia, boracite.	
ALUMINIUM	Wöhler.....	1828		Corundum, topaz, sapphire, emery, ruby, garnet, slates, clays, hornblende, asbestos, mica, felspar, chlorite, sulphate of alumina, wavelite (phosphate of alumina), alum, alum-stone, clay iron ore, and earth in general.	
SILICIUM	Berzelius.....	1824		Quartz, opal, calcined, flint, jasper, garnet, topaz, hyacinth, beryl, emerald, augite, felspar, hornblende, mica, soapstone, chlorite, sparingly in vegetables, in most rocks and earth and sand, some iron ores, in some hot springs, as the Geysers in Iceland, &c. next to oxygen, the most abundant of the elements.	
GLUCINIUM	Wöhler.....	1828		Euclase, beryl (aquamarine), emerald.	

Name.	Discovered by	When	Exists in Nature in
ITRURIUM	 Wöhler	 1828	Gadolinite, and some ores of cerium and columbium.
ZIRCONIUM	 Berzelius	 1824	Hyacinth, jargon, eudyalite.
THORIUM	 Berzelius	 1829	Thorite.
IRON, <i>n.</i>	 Known to the	ancients.	Native, in union with nickel in meteoric iron, iron pyrites (sulphuret of iron) ; specular iron ore, haematite, &c. (oxides of iron) ; clay iron ore (carbonate of iron) ; mixed with many other metallic ores ; augite, talc, felspar, mica, hornblende, soapstone, chlorite, and most ingredients of rocks ; most precious stones ; earth in general ; and sparingly in animals and vegetables.
LEAD	 Known to the	ancients.	Galena (sulphuret of lead), carbonate of lead, sulphate of lead, phosphate of lead, &c., and some ores of silver.
COPPER, <i>n.</i>	 Known to the	ancients.	Native, sulphuret of copper, copper pyrites (sulphuret of iron and copper), carbonate, muriate, phosphate, sulphate, arseniate of copper, and some other minerals.
ZINC	 Known to Pa-	racelus in	Blende (sulphuret of zinc), calamine (carbonate of zinc), &c.
ANTIMONY, <i>n.</i>	 Known to Basil	Valentine in 15th	Native, sulphuret of antimony, oxide of antimony, &c.

Name.	Discovered by When Known to the ancients.	Exists in Nature in
TIN	Known to the ancients.	Oxide of tin, sulphuret of tin, &c.
BISMUTH, <i>n.</i>	Known to Agricola ... 1530	Native, sulphuret, and carbonate of bismuth, &c.
MANGANESE	Gahn and Scheele. 1774	Oxide, sulphuret, carbonate of manganese, &c.
CHROMIUM	Vauquelin... 1797	Oxide of chrome, chrome iron ore (chromate of iron).
COBALT	Brandt..... 1733	Union with arsenic, and with arsenic and iron, &c.
ARSENIC, <i>n.</i>	Brandt..... 1733	Native, oxide of arsenic, sulphuret of arsenic (orpiment and realgar), cobalt ores, &c.
NICKEL	Cronstedt.... 1751	Native, and in ores with oxygen and arsenic.
VANADIUM	Sefström 1830	Some iron ores, and in vanadate of lead.
CADMIUM	Stromeyer ... 1817	Some ores of zinc.
TUNGSTEN	D'Elhuyart.. 1781	Oxide of tungsten, tungstate of iron, &c.
MOLYBDENUM	Hjelm..... 1782	Sulphuret and oxide of molybdenum, &c.
CERIUM	{ Berzelius and Hisinger... 1803	Union with fluorine, cerite (cerium, oxygen, iron, silica), &c.
COLOMBIUM	Hatchett.... 1801	Columbite (columbium, oxygen, iron, manganese), &c.
TELLURIUM	Müller..... 1782	Only in the state of a metallic alloy.
TITANIUM	Gregor..... 1791	Several minerals in union with oxygen, iron, manganese, silica, or lime.
URANIUM	Klaproth.... 1789	Oxide, phosphate of uranium, &c.

Name.	Discovered by	When Known to the ancients.	Exists in Nature in
MERCURY, <i>l. n.</i>		Known to the ancients.	Native, alloyed with silver, cinnabar (sulphate of mercury), horn quicksilver.
SILVER, <i>n.</i>		Known to the ancients.	Native, alloyed with antimony, sulphuret of silver, in ores with sulphur, iron, antimony, lead, copper, chlorine, &c.
GOLD, <i>n.</i>		Known to the ancients.	Native or alloyed with silver.
PLATINUM, <i>n.</i>		Wood, Ja- maica.....1741	Native, or alloyed with palladium, osmium, iridium.
PALLADIUM, <i>n.</i>		Wollaston...1803	Native, or alloyed with platinum.
RHODIUM.....		Wollaston...1803	In alloy with platinum and palladium.
OSMIUM.....		Tennant.....1803	} United in a natural alloy, also in alloy with platinum.
IRIDIUM.....		Tennant and Descotils 1803	

66. The following are the most abundant and extensively distributed ;—the others occur in so few minerals, and in such small quantities, that they may be disregarded in a general view of the Chemistry of Nature.

Non-metallic.	Metallic.
Oxygen	Potassium
Hydrogen	Sodium
Nitrogen	Calcium
Sulphur	Barium
Phosphorus	Magnesium
Carbon	Aluminium
Chlorine	Silicium
Iodine	Manganese
	Iron

67. Of these, only oxygen, nitrogen, sulphur, carbon, iron, are found native. The others are in combination with the preceding and with each other. The metallic elements are chiefly in union with oxygen. Oxygen is by far the most abundant element ; next silicium ; then aluminium, hydrogen, calcium, nitrogen, carbon, chlorine ; potassium, sodium, iron, magnesium, sulphur, are next in point of abundance ; then barium, phosphorus, iodine ; and nearly in the order in which they have been just enumerated.

68. Lead, copper, zinc, antimony, tin, bismuth, mercury, silver, gold, platinum, the most abundant of the substances commonly known as metals, occur in few situations, and in very small quantities, when compared with the preceding. The other elements occur very sparingly indeed.

69. The following are the elements found native :

Oxygen	Sulphur	Iron
Nitrogen	Carbon	Copper

Antimony	Mercury	Platinum
Bismuth	Silver	Palladium
Arsenic	Gold	

70. The following were the only elements known to the ancients in the uncombined state :

Sulphur	Lead	Mercury
Carbon	Copper	Silver
Iron	Tin	Gold

71. The substances around us as we find them in nature, may be divided into three kinds ; gaseous or aerial, liquid, and solid bodies. Of the first kind, there is only one with which we are at all familiar, namely "THE AIR." Of the second kind, liquid bodies, there is only one presented to us by nature which is common in every place, WATER, which forms the ocean, rivers, and lakes, and rises in springs out of the bowels of the earth, or descends to us from the clouds. Of the third class, solid bodies, there are two kinds, sufficiently distinct to strike every one as being essentially different ; those which have or have had life, called *organic bodies*, and those which have never been endowed with the principle of life, called *inorganic bodies*. Organic bodies consist of animals and vegetables ; inorganic bodies are the substances which compose the earth, rocks, stones, and all kinds of minerals or earths, as sand, clay, lime, &c. We shall examine in succession the nature and composition of these various bodies, in the order shown below :—

I. AIR, OR THE ATMOSPHERE.

II. WATER.

III. MINERAL KINGDOM.

IV. ORGANIC BODIES..... { 1. Vegetables.
 { 2. Animals.

CHAPTER III.

THE ATMOSPHERE.

72. The atmosphere, called also "the air," "atmospheric air," is that thin transparent gaseous substance which rests upon the surface of the earth, enveloping it on every side, revolving with the earth on its axis, and round the sun, and, like other bodies, preserved at its surface by the attraction of gravitation.

It is not, as was imagined by the ancients (who reckoned four elements, of which all things were composed, air, fire, earth, and water), an element: it is a compound, consisting of a great many different substances. But it was impossible that the ancients could have any knowledge of its nature, as they had no instruments adapted for any experiments with it, and were even unacquainted with the principles on which such instruments could be constructed. The term "air" is derived from the Latin word *aer*, which is from the Greek *ἀήρ*. The term "atmosphere" is derived from two Greek words, *ατμός* (*atmos*), vapour, and *σφαῖρα* (*sphaira*), a sphere or region, signifying the region of air next to the earth; and hence containing the vapours or exhalations arising from its surface—the region of vapours. This term is now used to express the whole mass of the air, to whatever height it may extend.

I. PROOFS THAT THERE IS SUCH A SUBSTANCE AS
THE AIR.

73. At first, we might suppose the air not to be a substance or body ; we walk in it and move every limb without any feeling indicating the presence of any thing. We cannot see nor touch it ; it has no taste or smell. On a calm day, one might be apt to say, on looking at a building at a distance, that there is *nothing* between him and the building—that the space between is empty ; but let him run, or be on the top of a coach going very fast, or even move the hand briskly, he will then have a feeling of some impression on his face or hand, like that of some light substance striking him, or like a gentle breeze. If, while running, he hold an open umbrella behind him, he will feel something resisting the advance of the umbrella, and rendering the exertion of force on his part necessary to pull it onwards ; while no such force will be required to carry the umbrella closed like a walking-stick in the hand. There must be some substance present which causes the impression on the face or hand, and resists the open umbrella while advancing. This substance is the air : it is invisible, so that we see nothing in the space which it occupies ; and we do not feel it on a calm day when we are moving slowly, because it is so extremely light, and its particles strike upon the face so gently and at comparatively long intervals. But when we move fast, the particles of air strike with a greater impetus, and hence produce a decided impression. When we attempt to draw the open umbrella along, we feel a great resistance, because the umbrella has to push such a large quantity of air before it ; when the umbrella is closed, it has to

TABLE OF THE ELEMENTS.

1. NOT METALLIC.

Name.	Discovered by When	Exists in Nature in
OXYGEN, <i>g. n.</i> ...	{ Priestley.....1774	Air, water, earths (including sand, stones, earth of every kind, and rocks), and organized bodies,—the most abundant of the elements.
HYDROGEN, <i>g.</i>.....	{ Scheele.....1775	Water, organized bodies, naphtha, petroleum, mineral pitch, asphaltum, jet, common coal, cannel coal, amber, sulphate of ammonia, muriate of ammonia (sal-ammoniac).
NITROGEN, <i>g. n.</i>....	Rutherford...1772	Air, animals, some vegetables, as fungi, cruciferae, nitrate of potash (nitre), nitrate of lime, nitrate of soda, common coal, sulphate of ammonia, muriate of ammonia (sal-ammoniac), some hot springs.
CHLORINE, <i>g.</i>.....	Scheele .....1774	Common salt (chloride of sodium), hence in sea-water, salt lakes and springs, rock-salt; sal-ammoniac (muriate of ammonia), horn silver (muriate of silver), muriate of copper, horn quicksilver, and some rare ores of lead, and in small quantity in animal substances, and in sea-weeds.
SULPHUR, <i>n.</i>.....	Known to the ancients ...	Native, in native sulphuric acid, gypsum, heavy spar, alum, alum-stone, iron pyrites, green vitriol; sulphurets of arsenic (realgar, orpiment), silver, copper, antimony, lead (galena), zinc (blende), quicksilver (cinnabar), bismuth, cobalt; and in small quantities in other minerals of less frequent occurrence,—sparingly in organic bodies.

Name.	Discovered by When	Exists in Nature in
SELENIUM,	 Berzelius.....1818	Some iron pyrites, and ores of silver, copper, and a few other metals.
BORON,	 Davy .....1807	Native boric acid, borax (tincal), datholite (borate of lime), boracite (borate of magnesia).
PHOSPHORUS	 Brandt.....1669	Animals, chiefly in the bones, wavelite (phosphate of alumina), apatite (phosphate of lime), bog iron ore, some other ores of iron, and in some ores of manganese, uranium, copper, lead.
CARBON, <i>n.</i>	 Known to the ancients...	
IODINE	 Courtois.....1812	Native, pure in the diamond, constitutes the greater part of mineral charcoal, plumbago or black lead, jet, every kind of coal, naphtha, petroleum, mineral pitch, asphaltum, amber; in clay-slate; also in limestone, marble, and every carbonate, as of magnesia, of baryta (withierite), of strontia, of soda (natron); clay iron ore, in some ores of bismuth, silver, copper, lead, zinc (calamine), and abundantly in all organic bodies.
BROMINE, <i>l.</i>	 Balard.....1826	Some salt springs, in the water of the Mediterranean, in sponges, some shell-fish, as the oyster, and in sea-weeds.
FLUORINE	.....	Sea water, water of the Dead Sea, many saline mineral springs, and sea-weeds containing iodine.
2. METALLIC.		Fluor spar (fluat of lime), and some rare minerals of alumina and cerium.
POTASSIUM	 Davy.....1807	Land vegetables abundantly, sea-weeds, and animals, mica, talc, felspar, chlorite, pumice, obsidian, soapstone, and other ingredients of rocks, nitre, alumstone, and some kinds of soil.

Name.	Discovered by	When	Exists in Nature in
SODIUM	Davy	1807	Sea-weeds, land vegetables and animals, sodalite, albite, pitchstone, pumice, obsidian, and other ingredients of igneous rocks, natron, sulphate of soda, nitrate of soda, borax, common salt.
LITHIUM	Davy.....	1818	Petalite, and a few other rare minerals.
CALCIUM	Davy.....	1807	Augite, hornblende, felspar, and other ingredients of rocks; slates, clays, earth, carbonate of lime (marble, limestone, &c.), fluor spar, gypsum, spatite, garnet, asbestos, bones and shells of animals, &c.
BARIUM	Davy	1807	Witherite (carbonate of baryta), heavy spar (sulphate of baryta).
STRONTIUM	Davy	1807	Arragonite, strontianite (carbonate of strontia), celestine (sulphate of strontia).
MAGNESIUM	Bussy.....	1830	Augite, hornblende, asbestos, talc, soapstone, chlorite, bitterspar, magnesian limestone, some clays, mica, carbonate of magnesia, sulphate of magnesia, boracite.
ALUMINIUM	Wöhler.....	1828	Corundum, topaz, sapphire, emery, ruby, garnet, slates, clays, hornblende, asbestos, mica, felspar, chlorite, sulphate of alumina, wavelite (phosphate of alumina), alum, alum-stone, clay iron ore, and earth in general.
SILICIUM	Berzelius.....	1824	Quartz, opal, calcedony, flint, jasper, garnet, topaz, hyacinth, beryl, emerald, augite, felspar, hornblende, mica, soapstone, chlorite, sparingly in vegetables, in most rocks and earth and sand, some iron ores, in some hot springs, as the Geysers in Iceland, &c. next to oxygen, the most abundant of the elements.
GLUCINIUM	Wöhler.....	1828	Euclase, beryl (aquamarine), emerald.

Name.	Discovered by	When	Exists in Nature in
ITTRIUM	Wöhler.....	1828	Gadolinite, and some ores of cerium and columbium.
ZIRCONIUM	Berzelius.....	1824	Hyacinth, jargon, eudyalite.
THORIUM	Berzelius.....	1829	Thorite.
IRON, <i>n</i>	Known to the ancients.		Native, in union with nickel in meteoric iron, iron pyrites (sulphuret of iron); specular iron ore, haematite, &c. (oxides of iron); clay iron ore (carbonate of iron); mixed with many other metallic ores; augite, talc, felspar, mica, hornblende, soapstone, chlorite, and most ingredients of rocks; most precious stones; earth in general; and sparingly in animals and vegetables.
LEAD	Known to the ancients.		Galena (sulphuret of lead), carbonate of lead, sulphate of lead, phosphate of lead, &c., and some ores of silver.
COPPER, <i>n</i>	Known to the ancients.		Native, sulphuret of copper, copper pyrites (sulphuret of iron and copper), carbonate, muriate, phosphate, sulphate, arseniate of copper, and some other minerals.
ZINC	Known to Pa- racelsus in 16th cent.		Blende (sulphuret of zinc), calamine (carbonate of zinc), &c.
ANTIMONY, <i>n</i>	Known to Basil Valentine in 15th century (1490).		Native, sulphuret of antimony, oxide of antimony, &c.

Name.	Discovered by When Known to the ancients.	Exists in Nature in
TIN	Known to	Oxide of tin, sulphuret of tin, &c.
BISMUTH, <i>n</i>	Known to Agricola ....1530	Native, sulphuret, and carbonate of bismuth, &c.
MANGANESE	Gahn and Scheele. 1774	Oxide, sulphuret, carbonate of manganese, &c.
CHROMIUM	Vauquelin...1797	Oxide of chrome, chrome iron ore (chromate of iron).
COBALT	Brandt.....1733	Union with arsenic, and with arsenic and iron, &c.
ARSENIC, <i>n</i>	Brandt.....1733	Native, oxide of arsenic, sulphuret of arsenic (orpiment and realgar), cobalt ores, &c.
NICKEL	Cronstedt....1751	Native, and in ores with oxygen and arsenic.
VANADIUM	Sefström ....1830	Some iron ores, and in vanadate of lead.
CADMIUM	Stromeyer ...1817	Some ores of zinc.
TUNGSTEN	D'Elhuyart..1781	Oxide of tungsten, tungstate of iron, &c.
MOLYBDENUM	Hjelm.....1782	Sulphuret and oxide of molybdenum, &c.
CERIUM	{ Berzelius and Hisinger....1803	Union with fluorine, cerite (cerium, oxygen, iron, silica), &c.
COLUMBIUM	Hatchett....1801	Columbite (columbium, oxygen, iron, manganese), &c.
TELLURIUM	Muller.....1782	Only in the state of a metallic alloy.
TITANIUM	Gregor.....1791	Several minerals in union with oxygen, iron, manganese, silica, or lime.
URANIUM	Klaproth.....1789	Oxide, phosphate of uranium, &c.

Name.	Discovered by When Known to the ancients.	Exists in Nature in
MERCURY, <i>l. n.</i>	Known to the ancients.	Native, alloyed with silver, cinnabar (sulphate of mercury), horn quicksilver.
SILVER, <i>n. n.</i>	Known to the ancients.	Native, alloyed with antimony, sulphuret of silver, in ores with sulphur, iron, antimony, lead, copper, chlorine, &c.
GOLD, <i>n.</i>	Known to the ancients.	Native or alloyed with silver.
PLATINUM, <i>n.</i>	Wood, Jamaica.....1741	Native, or alloyed with palladium, osmium, iridium.
PALLADIUM, <i>n.</i>	Wollaston...1803	Native, or alloyed with platinum.
RHODIUM.....	Wollaston...1803	In alloy with platinum and palladium.
OSMIUM.....	Tennant.....1803	} United in a natural alloy, also in alloy with platinum.
IRIDIUM.....	Tennant and Descotils 1803	

ends, this could not take place, for then the pressure of the air which acts through the water in an upwards direction, driving the liquid into the jar, would be exactly balanced by the pressure of the air, acting on the same water in a direct or downwards direction, through the opening in the top of the jar, and the water would not follow the jar out of the trough. Let us suppose that the jar B is full of water, and standing on the shelf of the pneumatic trough, and that, by turning the stopcock at the top, we open a communication between the interior of the jar and the external air. At the moment in which this opening is made, the liquid will begin to descend ; for the power which, acting from below, kept the water raised in the jar, being now exactly balanced by the same power being admitted to press from above, the water will be free to obey the laws of gravity, and it will therefore descend. Turn the stopcock so as to close the opening, and exclude the atmospheric pressure from above, the descent of the liquid will immediately cease, the gravity of the water being overcome by the pressure from below, which is not now resisted by pressure from above. In this situation the liquid is represented in the figure. In the same way the liquid in the jar A is supported.

81. We can now understand better what is meant by saying that the pressure of the air will support or is of the same weight as a column of water 33·87 feet high (76). If we suppose the jar A to be 33·87 feet high, the air would support the water in it when full, but if it were 40 feet high, as the air can only support it to the height of 33·87 feet, the space above that height would remain vacant. As, then, the gravity of a column of water 33·87 feet high just

balances the pressure of the air, we say that a column of water that height is just of the same weight as a column of air of the same diameter, and the whole height of the atmosphere. As mercury is much heavier than water, we should expect that the air could not support so high a column of the former. This accordingly we find to be the case ; a column of mercury about 30 inches high is of the same weight as a column of air reaching from the surface of the ground to the extreme limits of the atmosphere. The BAROMETER is merely a long narrow tube closed at one end, nearly full of mercury, and standing in the same situation in a vessel of mercury as the jars A and B in the pneumatic trough. The tube is more than 30 inches high, and hence, as the air can support mercury only to a height of about 30 inches, the space between the upper surface of the mercury and top of the tube will be a *vacuum*, that is, perfectly empty. Now, the pressure of the atmosphere is not always the same ; from causes which are not well understood, the atmosphere has a greater weight or pressure at one time than at another. Sometimes it is so light as to be able to support the mercury *only 28 inches*, while at other times it pushes it up to a height of about 31 inches. By having a scale of inches attached to the tube, we can read off at any time what is the height of the mercury, and thus judge of the pressure of the atmosphere at the time ; this is the use of the barometer, and it is a very valuable instrument ; for a great number of natural phenomena and artificial operations in which mankind are deeply interested, are modified by the varying pressure of the air.

Filling the jar with water and placing it on the shelf of the pneumatic trough is the first step towards filling the jar with any gas that may be required : the method of displacing the water and putting the gas in its place will be shown afterwards.

III. COMPRESSIBILITY AND ELASTICITY OF THE AIR.

82. The air and other gases are generally termed *elastic* fluids. When air is subjected to pressure, it yields to the pressure, its particles are brought nearer to each other, and it is contracted or occupies a smaller space than before. But the air resists this pressure, considerable force is required to press its particles nearer to each other, and when this pressure is removed, its particles separate from each other, and it resumes its original size. This separation of the particles of any body, so that it occupies a larger space, is called *expansion*. This property of yielding to a certain extent to the effects of pressure, and springing to its former condition whenever the pressure is removed, is called *elasticity*. It is found in all airs or gases, and hence such fluids are called *elastic*, in opposition to water and other liquids, which are not (or at least in a very small degree) compressible. Every elastic fluid, as air, is like a wound up or compressed spring, and is continually making efforts to expand and extend itself over a larger space. A quantity of air which occupies a space of 1000 cubic inches when pressed by a force equal to 1, will occupy the space of only 500 cubic inches if the pressure be increased to 2 ; and if the pressure be diminished to $\cdot 5$, the elasticity or repulsive principle getting more scope, the air will enlarge proportionally, and now occupy the space of 2000 cubic inches.

83. Since the air is heavy (has weight) like other bodies, the lower parts of the air will be pressed upon by those which are above. The consequence of this will be, that the particles of air in the lower regions next the earth will be much nearer to each other than those in the upper regions, for they are pressed upon by almost the whole of the atmosphere, while those above are pressed on only by that portion of the air which is higher still. The lowest strata of air will be the most dense or heavy; that is, *they will contain the greatest number of particles within any given space*; and the upper portions will be lighter in proportion to their height; for the higher they are, the less air is above pressing their particles together, till at the upper parts there is scarcely any pressure at all; the elasticity of the air is less controlled, its particles are thus driven asunder, and there must be a much smaller number of particles in a given space than in the same space nearer the surface of the earth; a cubic foot of air taken from the surface of the earth will therefore be much heavier than a cubic foot taken at the height of a thousand yards, or a mile. Gay Lussac filled a bottle with air at a height of about three miles when in a balloon, and when he descended, took out the stopper under water. The water rushed in and filled half of the bottle, the air in the bottle being compressed into less bulk by the greater pressure to which it was now exposed. This lightness or thinness of the air in the upper regions is expressed by the term "*rarity*;" and we say that the air gradually becomes more *rare* as it is farther from the surface, and more *dense* as it is nearer the ground. In the higher regions, the air is extremely rare: in

the lower strata its density varies with the height of the mercury in the barometer. (81.)

84. It is this elasticity that preserves the air in its gaseous form. At the surface of the earth, the pressure is not sufficient to overcome the elasticity which keeps the particles asunder (although every cubic inch there has a force of about 14·7 pounds pressing on it), and hence the air remains gaseous.

IV. HEIGHT OF THE AIR.

85. It is not known exactly what is the height of the atmosphere. The ancients imagined that it reached to the moon. But it is now considered that the atmosphere is *limited*, that it does not extend indefinitely through the regions of space. From the rate at which the air will expand as it is farther removed from the surface, and from some reasons deduced from the duration of twilight, it has been conjectured that the height of the atmosphere cannot much exceed from 40 to 50 miles. At the height of $44\frac{1}{2}$ miles, the air is sufficiently dense to refract the light of the sun, so that we have light for some time after the sun has sunk below the horizon, or twilight. And it is conjectured that the air must extend a considerable height above this. Had air been of the same density, at whatever distance above the surface, it would be easy to calculate its height; for we know that a column of the whole height of the air is of the same weight as a column of mercury of equal diameter and 30 inches high. If, then, the particles of air were everywhere at the same distance, we would infer that the air is as many times higher than the column of mercury, as air is lighter than mercury; air is about 11065 times lighter than

mercury ; so the air would then be about 5 miles in height. But the increased distance of the particles in the higher regions sets aside this simple calculation.

V. COLOUR OF THE AIR.

86. When we look at the sky on a clear day, it appears like a large light blue arch set over our heads, and seen through the (supposed) invisible substance called air. But this is not the case : there is no blue dome above us, and when the sky is viewed from any elevated region of the earth, as the top of a high mountain, or in a balloon, and where we would expect that this supposed blue vault would be more distinct, and manifest its blue tint more decidedly—it appears not more blue, but dark or black. In proportion as the spectator rises above the surface of the earth, *and has less air above him, and that very rare* (83), the blue tint gradually disappears, and if he could attain a height at which there is *no air*, the sky would be perfectly black—there would be total darkness all around—except in the direction in which the sun's rays fall upon him. This is the appearance which, from the laws of optics, it is known would be presented where there is no air : and the observations of travellers who have ascended to great elevations on the Alps or the Andes confirm this. Again, when we look at any distant mountain on a tolerably clear day, it will appear of a blue colour, somewhat like the sky, but a little deeper in the tint ; and yet when we approach the mountain, we see that it is of a very different colour. When we look at a forest not very far from us, it appears of a green colour ; but if we recede to a great

distance from it, it will acquire a bluish tint, which gradually deepens as our distance from it increases.

87. In these cases, then, it is seen that where there is very little air, the sky has only a very slight tinge of blue, and that the strength of this blue tint diminishes as the quantity of air diminishes; and also that when we look at any very distant object, looking at it of course through a thick body of air, that object appears of a blue colour. If not itself of this colour, it must acquire the hue from being seen through a blue-coloured medium. These well established facts lead naturally to the inference that *the air itself is of a blue colour.*

88. But how does it happen that we see this blue colour of the air only when we look at the sky, or at a distant mountain or forest? Why is not the blue colour seen in the air surrounding us when we look towards a house or wall not so far removed, or even in the air in a room, or in the air contained in what we call an empty glass vessel? A very simple experiment will explain the reason of this apparent anomaly. If we take any large glass vessel which contains a coloured liquid of a deep colour,* and have several glass tubes of different diameters, from an inch to a 10th or 20th of an inch, and fill these tubes with liquid out of the large vessel; though we have the same liquid in all, and hence in all the matter which causes the colour, it will be seen that the tint will gradually become more faint in proportion as the diameter of the tube is less, until, in the smallest, the liquid is clear and colourless like water.

* A solution of the nitrate of copper, or of blue vitriol, sufficiently diluted, will give a colour very nearly approaching the azure tint of the sky.

89. Here then, it will be observed, that the intensity of the colour is just in proportion to the mass at which the spectator looks ; and that a very small quantity, of that which in large quantities has a strong colour, does not present any colour at all. This is the case with all semi-transparent substances ; a small quantity cannot transmit to the eye a sufficient body of their peculiar colour to make an impression, and hence appears colourless. The air is a substance of this nature : and thus, though the great body of air which is opposed to us, when we look at a clear sky or any distant object, transmits a sufficient quantity of blue rays to produce an impression of that colour on the eye, the small quantity in a glass, in a room, or even within the compass of a few miles, cannot convey enough of blue rays to the eye to produce the colour which the air manifest in a large body.

90. The differences in the depth of the blue tint which are observed at different times and places, its faintness at the horizon as contrasted with its appearance at the zenith (above our heads), its increasing depth in the torrid zone, and faintness at sea, depend upon the varying quantity and transparency of the watery vapour in the air. Indeed, it is upon this ingredient of the air that the blue colour is supposed to depend.

VI. CHEMICAL COMPOSITION OF THE AIR.

91. The discovery of the composition of atmospheric air is one of the most brilliant of modern times. The air was regarded as an *element* by the ancients ; it has now been proved to contain two very different gases, oxygen and nitrogen, besides

small proportions of other matters. But we need not be surprised at the ancient opinion regarding a body, the very existence of which is not palpable to the senses, but must be determined by a process of reasoning. A substance so thin and subtile, so light, transparent, and invisible (as they considered it), might very naturally be looked upon as one of the elements; and it is certainly one of the just boasts of modern science that we should be able to show, and prove by the most irresistible arguments, that this substance, simple as it may appear, consists of several various kinds of matter; to separate it into these, and show them by themselves; or to take them, mix them up in proper proportions, and thus form artificially a substance similar to air.

92. For the discovery of the constitution of the atmosphere we are indebted to Scheele and Lavoisier, two eminent chemists of the last century. The two following experiments, performed and described by Lavoisier, give the most complete and satisfactory proof we can have of the nature of atmospheric air.

1. *Division of Atmospheric Air into two Gases, OXYGEN and NITROGEN, one which causes Respiration and Combustion to go on with too great activity, another in which these processes cannot go on at all.*

93. Lavoisier took a certain quantity of the liquid metal called mercury or quicksilver, and exposed it to a strong heat in a glass flask along with a certain quantity of air. The mercury was kept in the flask for twelve days, at a temperature near to that at which it boils, and though not boiling was continually evaporating, that is, being turned into an

aëriiform body or vapour by the heat. This was known by the internal surface of the vessel being covered with small drops of liquid mercury; the vapour which arose from the surface of the mercury being converted into liquid mercury again when it struck against the sides of the vessel, which were not so hot as the liquid below. When these small globules of mercury increased to a sufficient size, they fell back into the mass at the bottom of the vessel. "On the second day," says Lavoisier, "small red particles began to appear on the surface of the mercury; these, during the four or five following days, gradually increased in size and number, after which they ceased to increase in either respect. At the end of twelve days, seeing that the calcination of the mercury did not at all increase, I extinguished the fire,"—and the materials were examined after they had cooled.

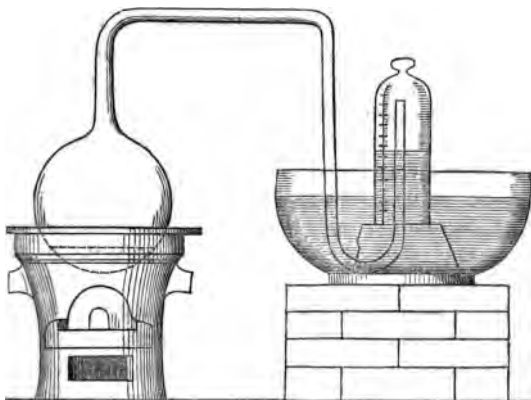
94. Decided changes had been effected on both the air and the mercury. The air had diminished one-sixth in bulk and rather more than that in weight; a lighted candle or other body in a state of combustion was extinguished when placed in the air (gas) which was left; and any small animal immersed in this air was killed (suffocated) almost immediately. Here were three changes on the air; so much had disappeared: the remainder would not support the combustion of a candle; and was unfit for the respiration of animals. The air at first in the flask seemed to have lost that ingredient to which air owes its power of supporting combustion and respiration. The quicksilver was also changed; when put into the flask, it was liquid, of a white

colour, and a bright metallic lustre. When taken out, it (or so much of it) was converted into earthy scales of a reddish colour, having entirely lost the fluidity, white colour, and shining lustre; and it had become heavier, *having increased in weight just as much as the air had diminished in weight.** There were only two substances to act upon each other; one had diminished in weight; the other had acquired additional weight (that is, an additional quantity of matter of some kind had been added to it); hence the very natural inference that *the matter, whatever it is, that the air had lost, was that which had been added to the mercury.*

95. The following figure will illustrate this elegant experiment. At the left is seen the furnace with a sand-pot, which is a semispherical iron vessel containing sand, in which the flask (called also matrass) containing the quicksilver is placed. The flask is heated by the sand, which derives its heat from the fire below the pot. The stem of the flask is lengthened out into a long bent tube, which passes into a jar or receiver placed on a stool in a pneumatic trough filled with quicksilver. After the flask and stool have been adjusted, the jar, full of air, is set on the stool, and then by means of a bent tube so much of the air is sucked out of the jar and flask.

* The red earthy matter is known by the names of red precipitate—precipitate per se—red oxide of mercury—peroxide of mercury. It consists, in 216 parts, of 200 of the metal and 16 of oxygen.

Fig. 3.—*Lavoisier's Experiment showing the Composition of Air.*



96. At the same moment in which the air is removed, the quicksilver rises in the jar, being pushed up by the atmospheric pressure. The quicksilver cannot rise before some air is removed, because, though the atmosphere is pressing on the mercury in the trough, and tending to push it upwards into the jar, the internal air is as dense as its elasticity (82) would permit; but when so much of the air is removed (its elasticity and the atmospheric pressure causing it to expand and rush into the vacant space in the expanded lungs, with which it communicates by the tube), the atmosphere having then less air in the interior resisting its pressure, pushes up the quicksilver just in proportion to the quantity of air withdrawn. In this manner air is removed.

till the quicksilver rises to about two-thirds of the height of the jar.

97. The use of this apparently complex apparatus is as follows : if the air in the flask were not confined (as it is by the quicksilver in the jar), it could not be known how much air had been used in the experiment. If the vessel were tightly corked, this would be even worse than leaving it open, for it would be burst. Heat, it must be remembered, is the repulsive principle, and when the heat of the furnace enters the air in the flask, it repels its particles, causing it to expand and occupy a much larger space ; so much so, that the vessel would be burst were there no room for the expanded air. But, when arranged in the manner shown above, the air, as it expands from the heat, finds room for itself by pushing down the quicksilver in the jar ; and though of much less density than the external air, is now able to overcome, to a certain extent, that pressure which supports the quicksilver in the jar. But, whenever the air in the interior loses heat, or cools, so much of its elastic power leaves it ; the atmosphere, continuing to press, and having a less force resisting it interiorly, again pushes up the quicksilver. In this way there is ample room for the expansion of the air, without a single particle being allowed to escape. When the whole apparatus is as cool as the surrounding air, the quicksilver rises higher than at first, for so much of the air has diminished very much in bulk in passing to the solid form. By noting the increase of height in the quicksilver, we ascertain how much of the air has been condensed in the red scales which appear.

98. The mercury in its altered state must next

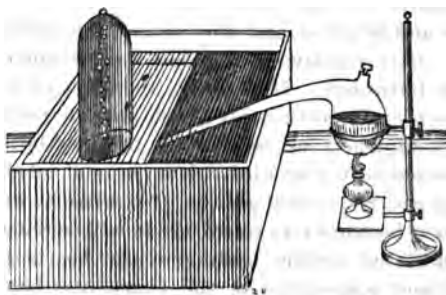
be examined ; it must be attempted by some means to get from these earthy scales the matter they have absorbed from the air, that we may procure this matter by itself, and thus be able to examine its properties. By the influence of chemical attraction operating between the mercury and an ingredient of the air, they had combined and formed the red scales. This compound must be decomposed, to recover, if possible, the lost air. Lavoisier placed these red scales in a small glass retort and exposed them to heat, the apparatus being arranged in such a manner that any gas which came from the red scaly matter would be driven into a jar standing in a pneumatic trough.

99. The general form of a retort is seen in the figure in page 18, and the figure below (fig. 4.) The vessel at the right side, consisting of a globe of glass, terminating in a long tube, is a retort. The globular part is called the body of the retort. Some retorts, as that represented below, have an opening at the top for admitting the materials to be used into the body ; such retorts are called *tubulated* ; the opening is called the *tubulure*. When it is desired to collect a gas from a retort, the end of the tube (the beak) must be made to dip into the water in a pneumatic trough, a jar full of water being placed over the beak of the retort. When the gas has begun to be disengaged from the matter in the body of the retort, as it occupies a much greater space in its new form than in the solid or liquid state, and must find room for itself somewhere, it pushes out of the retort (by the opening at the beak) the air previously in the retort ; the air thus pushed into the water cannot remain in that situation ; it rises perpendicularly upwards in the same way, and for

70 METHOD OF PROCURING OXYGEN FROM AIR.

the same reason as a cork plunged in water rises to the surface—namely, that it is lighter than the water. If there be no vessel at the surface of the water, the air or gas thus driven out of the retort would escape into the atmosphere ; but if there be a vessel full of water placed over the point at which the gas would escape from the water into the air, the gas will rise in bubbles to the top of that vessel. In collecting gas, then, from a retort, we allow as many bubbles to escape into the atmosphere as we guess make up the air which was in the retort at first—that is not what is wanted ; then we collect in the jar (receiver) full of water the gas which comes away. The following engraving will illustrate the manner in which a gas is prepared in a retort, and collected in a pneumatic jar :—

Fig. 4.—*Method of collecting Gas from a Retort.*



100. In Lavoisier's experiment, a very small retort was used, and it was heated in a manner somewhat similar to that in which the flask was *heated*. The heat applied was considerably greater

than in the experiment in which the mercury was converted into red oxide.

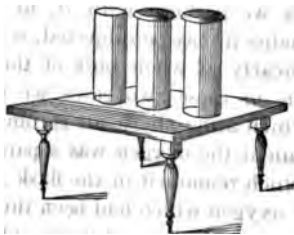
101. Upon exposing the red scales to heat, then, the following result was obtained ; *they were converted into metallic mercury* (exactly similar to that which had been placed in the flask) *and a thin colourless aerial matter, equal in bulk to the air which had disappeared, which collected in the top of the receiver.* The quicksilver having returned to its former condition, lost the additional weight it had acquired by abstracting something from the air, and given out at the same time a gaseous substance, Lavoisier concluded that the gas thus obtained was that which the mercury had abstracted from the air.

102. Upon examining this gas, it was found to be very different in its properties from air, and from the gas which was left in the flask (94). When a lighted candle is immersed in this gas, it burns with far greater brilliancy than in air, the flame being larger and brighter, and the combustion going on much more rapidly, so that the candle would be sooner burnt out. If a candle, the flame of which has been extinguished, but which has still some red particles in the wick, be placed in this gas, the flame will be actually rekindled. If an animal be placed in this gas, respiration goes on for a while as in air, but soon becomes very hurried, while the circulation (as indicated by the beating of the heart, quick pulse, and appearance of the eyes), also becomes rapid, the whole system is greatly excited, extreme weakness and death soon follow. But any animal will live much longer in a small and *limited* quantity of this gas than in the same quantity of atmospheric air. *It was also found by Lavoisier, that*

the quantity of gas procured from the red scales in the last experiment exactly corresponded to the quantity of gas which had disappeared from the air in the first.

103. The characters of these two gases, as contrasted with air and with each other, may be illustrated by the following experiment. Have on a stool three jars; one open, containing common air, the one next it, in the middle, containing the gas which extinguishes flame, and the third containing the gas which gives increased brilliancy to flame. Let the open ends of the two latter have trays on them to confine the gas, as in fig 5. Place a lighted candle in the open one containing air—the candle will burn as usual. Then place it in the middle jar, lifting the tray off, and putting the candle in and out quickly. The candle will be extinguished; and if put into the third jar while there is the least red spark left on the wick, the candle will be rekindled and burn with great splendour. If done quickly, this may be repeated several times.

Fig 5.



104. The gas which remained in the flask has been called "NITROGEN," being an ingredient in

nitric acid, and also "AZOTE;" the latter term being derived from two Greek words α (a), "not," "without," and $\zeta\omega\eta$ (zoe), "life," because it is unable to support life. It was at one time called "phlogisticated air," but now most commonly receives the name of "nitrogen." Its specific gravity is 0.972, and 100 cubic inches weigh 30.16 grains.

105. The gas procured from the red scales by heating them is called "OXYGEN," this term being derived from two Greek words, $\acute{o}\xi\upsilon\varsigma$ ($oxus$), "sour," "acid," and $\gamma\epsilon\nu\nu\alpha\omicron$ ($gennao$), "I form" or "generate." This name was given to it by Lavoisier, because it was believed to enter into the composition of all the acids, and be the cause of their acidity. It has been called "dephlogisticated air," "pure air," also "highly respirable air," "empyrean air," "vital air," from its power of supporting respiration. It is now always called "oxygen." Its specific gravity is 1.102, and 100 cubic inches weigh 34.109 grains.

106. These two gases are simple substances; they have never been decomposed or resolved into any other kind of matter: also, atmospheric air, whatever experiments we perform with it, to the action of whatever bodies it may be subjected, is always found to contain nearly its whole bulk of these two gases. Hence, then, in these two gases we have the *elements* of which atmospheric air is composed: by the first experiment the oxygen was separated from the nitrogen, which remained in the flask; while in the second, the oxygen which had been thus taken away was separated from that substance which removed it from the air, and procured by itself.

107. Having thus decomposed a quantity of air,

and resolved it into these two gases with such very opposite properties, one which instantly puts a stop to respiration and combustion, and another which supports both much more energetically than the air, let us try what would be the effect of mixing these two gases together. We would of course expect that the aerial substance so formed would be the same as air, and would manifest all the properties of air; and this is found to be the case. When the quantity of nitrogen left in the flask is mixed with the oxygen procured from the red scales, we now *recompose* the air we had decomposed, and if a lighted candle be placed in it, or a small animal be immersed in the air thus artificially made, combustion and respiration will go on just as in common air. The method of mixing gases will be shown afterwards. In the air thus made, a candle is not extinguished, as in nitrogen alone; it burns, because oxygen is present; but it does not burn with such rapidity and brilliancy as in oxygen alone, because it receives fewer particles of oxygen at a time, in consequence of the nitrogen which is present. In the air thus made, or in common air, a candle burns exactly in the way in which we should expect from the proportions and opposite qualities with respect to combustion of the two gases of which it is composed.

108. These experiments illustrate the meaning of two terms frequently employed by chemists, and signifying the two methods by which the composition of any compound body is proved, namely, ANALYSIS and SYNTHESIS. When the compound is decomposed, and resolved into its constituent parts (65), and these procured in a separate state, the opera-

tion is called *analysis*. This word is from the Greek word *αναλυω* (*analuo*), "I resolve," *i. e.* unfold any matter so as to discover its composition, which is from *ανα* (*ana*), "apart," and *λυω* (*luo*), "I dissolve:" thus, analysis signifies the separation of a compound into the parts of which it consists. In the above example with air (106), we prove its composition by analysis (analytically) when we separate from each other the oxygen and nitrogen of which it is composed. On the other hand, when we take the substances of which a compound body is composed and form the compound by uniting them, the operation is termed *synthesis*. This word is from the Greek word *συν* (*sun*), "together," and *θεσις* (*thesis*), "a position," which is from *τιθημι* (*tithemi*), "I put." Thus, synthesis signifies the act of joining or putting together. In the above example, taking oxygen and nitrogen in the proper proportions, mixing them, and thus making air, is proving the composition of the air by synthesis (synthetically).

109. These two gases are the main ingredients in atmospheric air. Of 100 parts of air, estimated by weight, these two gases form 98·87 parts, the rest (1·13) being carbonic acid gas and watery vapour, as will be seen afterwards: of these 98·87 parts, 75·55 parts are nitrogen gas, and 23·32 are oxygen. Estimated by measure, the proportion of carbonic acid and watery vapour would be 1·5, and of nitrogen and oxygen 98·5, in the following proportions, nitrogen 77·5 to oxygen 21, for oxygen is a little heavier than nitrogen. The following is a tabular view of the proportions of the different ingredients:

COMPOSITION OF ATMOSPHERIC AIR.

	By Measure.	By Weight.
Nitrogen . . .	77.5	75.55
Oxygen . . .	21.	23.32
Carbonic acid . .	0.08	0.10
Watery vapour . .	1.42	1.03
	100 parts.	100 parts.

Some chemists say that the relative proportions of nitrogen and oxygen, estimated by bulk, are 80 of the former, and 20 of the latter, or as 4 to 1. Viewed in this way, the relative weights and bulks of the oxygen and nitrogen in air would be as follows :—

Proportions of Oxygen and Nitrogen in Air.

Name of Gas.	Weight.	Bulk.
NITROGEN . . .	14 . .	
NITROGEN . . .	14 . .	
OXYGEN	8 . .	
ATMOSPHERIC AIR .	36	

The bulk of atmospheric air represented below the line by the two squares and the half square, consists, as shown above the line, of proportions of nitrogen and oxygen, the bulks of which must be

represented by two squares for the nitrogen, and a half-square for the oxygen. Stating the proportions by weight, each square of nitrogen will be represented by the number 14, while the number 8 will represent the weight of the half-square of oxygen, oxygen being heavier than nitrogen; 36 parts of atmospheric air consisting of 28 parts of nitrogen and 8 of oxygen. Generally speaking, we may say that about 1-5th of the air consists of oxygen, and that the rest is nitrogen.

110. It will be asked, is there no easier or simpler way of showing the composition of air than that practised by Lavoisier, which requires such a length of time for completing all the experiments, and such a complex apparatus? There is no easier way in which the oxygen can be extracted, but there are many other ways of procuring the nitrogen, which may be practised with a very simple apparatus.

111. A candle is extinguished in nitrogen, but burns more brightly in oxygen; from this we may reasonably infer that it is by means of the oxygen that the candle is enabled to burn in air. It is the same with all other bodies undergoing combustion or burning in the air: *it is the act of chemical union of the burning body with the oxygen of the air in which the burning consists.* From this we may derive a mode of abstracting oxygen from air—namely, to burn some combustible substance in a limited quantity of air. The combustible body employed must be one which forms with the oxygen a matter which can be easily separated from the nitrogen which remains. Phosphorus, a very inflammable substance, is generally employed for this purpose, and the experiment is one easily performed,

and not requiring any complex or expensive apparatus.

112. Take a piece of phosphorus about the size of a pea, let it be well dried by bibulous paper, and place it on a shallow copper cup. The copper cup with the phosphorus is to be set on a stand (such as that represented beside the jar B in the figure in page 54), on the shelf of a pneumatic trough. With one hand apply a light to the phosphorus, and, at the moment in which it begins to burn, place over it with the other hand an *empty* jar (of course *full of air*), setting it on the shelf of the trough, which is always understood to be covered with water. In this way, the air being enclosed on all sides, the phosphorus burns in a limited quantity of air. In this experiment the first thing observed is the escape of a quantity of air from the jar, coming out in bubbles through the water. But this soon ceases, the water is observed to rise in the jar, and the upper part of the jar is cloudy, being filled with opaque vapours. The combustion is not extinguished by the water rising, as it does not cover the copper cup; it floats and is raised by the water. When the jar has stood for some time after the combustion of the phosphorus has ceased and the whole apparatus has cooled, these vapours disappear, the gas left in the jar becomes clear and colourless, and it will be found that the water has risen to a considerable height, perhaps 1-3d or a little higher.

The first thing observed in this experiment is the escape of air from the jar; this is caused by the expansion of the air (57) from being heated by the burning of the phosphorus; so much is necessarily expelled. Next, we see the jar filled with opaque

vapours ; these are formed by the union of the phosphorus with the oxygen of the air ; *pyrophosphoric acid* is the name which they have received. The jar now contains a mixture of these vapours with nitrogen. The burning soon ceases, all the oxygen being *consumed*—that is, in the present case—combined with phosphorus. In a short time these vapours disappear, for they are gradually absorbed by the water, water having an affinity for the acid matter produced by the union of phosphorus and oxygen. Lastly, while the vapours are disappearing, the water rises in the jar ; the *pyrophosphoric acid* being now, by combining with water, condensed into the liquid state, occupies much less bulk than when in the state of vapour, and much less bulk than the oxygen which is now contained in it did when forming part of the air. Thus, as there is less gas interiorly resisting the pressure of the atmosphere, the liquid is raised just in proportion to the quantity of gas withdrawn (96). If no air had escaped from the jar at first, the water would rise only to 1.5th of the height of the jar, that being the proportion of oxygen (109). But as a considerable quantity of air was expelled by the heat, the water is raised somewhat higher. The absorption of the vapours may be accelerated by transferring the gas from one jar to another through water, in the manner which will be explained immediately. If we examine the gas which is left, it is found to exhibit all the properties which characterize nitrogen (94).

113. This experiment may be performed without losing any of the air, by employing a less quantity of air. Let the jar contain only 2-3ds of its bulk of air, the rest being water, and let the stand with

the phosphorus be set in the jar before the phosphorus is ignited. The phosphorus may then be set on fire through the jar, and without displacing it, by means of a burning glass, when the expanded air will find sufficient room for itself by pushing down the water, and thus none will be lost.

114. By means of phosphorus, the oxygen may be removed from air without setting fire to the phosphorus. If a long stick of this substance be placed in a jar of air confined over water, the phosphorus will unite slowly with oxygen, and thus abstract it from the air by undergoing what is called a *slow combustion*. The phosphorus emits a white vapour, and is slowly consumed as long as there is oxygen for combination. But 20 or 30 hours must be allowed for the completion of the experiment when done in this way. In this case, a mixture of phosphorous and phosphoric acids is produced, which is condensed by the water in the same way as the pyrophosphoric acid (112). The nitrogen prepared by phosphorus from air, contains a small quantity of phosphorus in vapour, about 1-40th of the bulk of the nitrogen, and a little carbonic acid. These may be separated from the nitrogen by agitating it with some aqua potassae (solution of caustic potash).

115. By boiling together for some time a little quick lime (or caustic potash), sulphur, and water, a dark-brown liquid is procured (a solution of sulphuret of calcium, or of sulphuret of potassium, if potash be used), which has the property of combining with oxygen, and may thus be used to abstract it from the air when we wish to procure nitrogen. If a little of this liquid be placed in a bottle which is then tightly corked, and the bottle be occasionally

shaken, the oxygen of the air in the bottle will be absorbed, and upon taking out the cork under water, water will be forced in, in proportion to the quantity of oxygen gas which has passed into the liquid state. The gas remaining in the bottle will be nitrogen. This is one of the experiments by which Scheele proved the composition of the air.

116. If equal weights of flowers of sulphur and iron filings be well mixed with each other, made up into a paste with a little water, and heated for a short time, the compound thus formed will have the power of abstracting oxygen from the air.

117. There is another mode by which oxygen may be removed from air, and which makes a highly interesting experiment. There is a gas mentioned in paragraph 21, which produces ruddy vapours with the air whenever they meet. This is *nitric oxide gas*, or *binoxide of nitrogen*, and is procured by the action of copper on aquafortis. It has a great attraction for oxygen, and forms with it ruddy fumes, consisting of *nitrous acid*, and which are condensed by water in the same way as the pyrophosphoric acid vapours (112). To abstract the oxygen from a quantity of air by means of this gas, let a jar be taken, the contents of which, by marks at the side, can be divided by the eye into seven equal parts. Let five of these be filled with air, and the other two with water, the mouth of the jar being under water in the pneumatic trough. Pass into this vessel as much nitric oxide as is equal in bulk to two parts, that is, enough to fill up the jar with gas, five parts being already occupied with air. Whenever the nitric oxide has ascended through the water and mixed with the air, the interior of the jar will be filled with red fumes ; and although as much gas has been

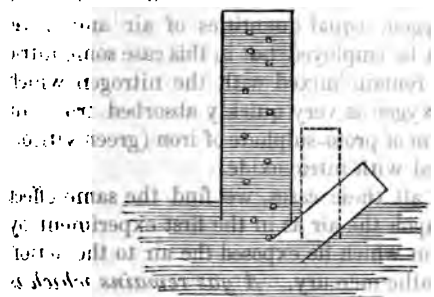
added as we would suppose should completely displace all the water, the water will gradually rise into the jar, and actually occupy *more* of the jar than before the nitric oxide gas was added to the air. Soon, especially if the jar be agitated a little so as to bring the water in contact with the gases, the interior will again become clear and colourless; and then it will be found that the water occupies about *three* of the seven parts, while the gas left now occupies only *four*. There were at first five parts of air in the jar, and of this we know that one part consists of oxygen. The remaining four parts are nitrogen, for the quantity of nitric oxide added was nearly sufficient to combine with all the oxygen of the air used, and form a matter which is entirely absorbed by the water. The proportions just given do not always remove all the oxygen; but they answer sufficiently well for an illustrative experiment, and all the nitric oxide is converted into a matter which is absorbed by water, so that it is entirely removed. If we wish to remove the whole of the oxygen, equal quantities of air and nitric oxide must be employed, but in this case some nitric oxide will remain mixed with the nitrogen which is left.—Oxygen is very quickly absorbed from air by a solution of proto-sulphate of iron (green vitriol) impregnated with nitric oxide.

118. In all these cases, we find the same effect produced upon the air as in the first experiment by Lavoisier, in which he exposed the air to the action of the metallic mercury. *A gas remains which is distinguished chiefly by its negative properties, being unable to support combustion or respiration.* In the second experiment of Lavoisier, it was proved that the matter which the mercury had absorbed

from the air, was a gas possessed in a very high degree of those properties which distinguish air. Although in the other cases just mentioned we cannot so easily procure the oxygen from the substance formed during the experiment, it has been demonstrated by experiments and analogy, that in all these cases the substance used to decompose the air and leave nitrogen, had abstracted oxygen; so that they confirm the account of the composition of air which we derive from the two experiments by Lavoisier.

119. The method of transferring a gas from one jar to another, or of mixing them in particular proportions, will be understood from the following figure: Let it be supposed, that the small jar is full of a gas, and that it is desired to transfer the gas from it into the large jar. The large jar must first be filled with water (79), and placed on a stool on the pneumatic trough with a hole in the middle, or above the hole on the shelf, or held by the hand in the water.

Fig. 6.—*Method of transferring Gases.*



The small jar containing the gas is then to be brought close to the large jar, holding it perpendicularly, and

depressed in the direction shown by the dotted line, till its mouth is a little below the level of the mouth of the large jar; the small jar is then to be moved gently into the other position seen in the figure, when the gas will escape from it, and rise into the large jar, if the latter be held directly over the point at which the gas escapes from the small one: by continuing to depress the top of the small jar till it assume the horizontal position, all the gas will be transferred into the other jar.

120. The method of mixing the nitric oxide gas with air will now be readily understood, and some idea may be formed of the method of operating with gases. It will be seen how, by means of the pneumatic trough and jars, for which we are mainly indebted to Hales and Priestley, we can in a manner subdue these apparently wild, subtile, and untamable bodies, the gases; catch them, confine them, and experiment with them; transfer them from place to place; divide and measure them with as much precision and minute accuracy as is practised by the apothecary with the more powerful medicines which he dispenses in drops or fractions of a grain.

121. It also will be understood how the pneumatic trough and jars are so valuable as a means of chemical research, and how, by means of them, *we have acquired a knowledge of a new set of substances, of which our ancestors had scarcely any idea, namely the airs, or gases.* Every one is acquainted with the two common forms in which matter exists, the solid and the liquid, as iron and water; but we are not so familiar with gaseous or aeriform bodies. They are not so palpable as solid and liquid substances, being, in general, clear, colourless, and

invisible. The pneumatic trough, by which we discover and experiment with them, could not be known to the ancients, as they were unacquainted with the pressure and elasticity of the atmosphere, the principles on which it depends. But, as soon as this apparently simple instrument was invented, a new world of interesting and important knowledge was opened to our view, one which was formerly not only unexplored, but of which even the existence was unknown. Within a very few years after the discovery of the pneumatic trough, a multitude of new gases were discovered, and it was found that there is a great variety of them, all characterized by peculiar properties, in the same way as there is an infinite variety of solid and liquid bodies. Of these gases, many are directly applied to important practical purposes : but perhaps their use in this respect is not so important as their *indirect* use in assisting the chemist in his examination of the properties of other bodies ; for the gases are a valuable means of chemical analysis. Of these aerial bodies, to take a few examples :—There are several which extinguish flame, and are fatal to animals immersed in them ; such are nitrogen and carbonic acid : others cause a flame to burn more brilliantly than in air ; such are oxygen and nitrous oxide : and the latter (the laughing gas) produces a kind of intoxication in any person who breathes it : another (phosphuretted hydrogen) presents the extraordinary phenomenon of taking fire whenever it meets with the air : another, transparent and colourless, produces a dense red smoke whenever it meets with the air : another (hydrogen), from being extremely light, was employed to fill balloons ; this gas is also

combustible, and burns with a reddish flame: others burn with a beautiful blue flame, as cyanogen and carbonic oxide: another (sulphuretted hydrogen) is employed to detect poisons: others (nitrous acid, nitric acid, muriatic acid, and chlorine,) are used to destroy contagious effluvia floating in the atmosphere: the last of these is now universally employed in bleaching: and there is another gas with which we are all familiar (coal gas), which is distributed in tubes all over the cities and even villages of modern times, sold in measured quantities, like any other article of commerce, employed to give a bright, steady, and manageable light for our streets, shops, and dwelling-houses, and now beginning to be used in almost every operation where heat is required. Not many years ago these were quite unknown even to the chemist, so rapid has been the progress of discovery in this previously unknown region, since the means of exploring it were obtained;—and now they are in daily use in the arts and manufactures, and even in domestic operations. Those which have been enumerated are but a part of what are known to the chemist; and every day is adding to their number, and increasing their usefulness, by pointing out some new application. The important results to which the pneumatic trough has led, give it a claim to a large share of our attention, for its discovery may be considered as the commencement of a new era in the science of chemistry; while there are few chemical or mechanical operations that afford a more striking illustration of the power over the bodies around us with which knowledge arms us, than the control which chemists have acquired over these light, invisible, volatile, fickle, and fleeting

bodies, the gases. What the poet's pen does with "the forms of things unknown," which his "imagination bodies forth," the chemist with the pneumatic trough, does with these apparent nonentities, the gases; he

"Turns them to shapes, and gives to airy nothing
A local habitation and a name."

122. Oxygen, besides forming one-fifth part of the air, exists largely in almost all other bodies, forming eight-ninths of water, about one-half of earthy matters, and is also abundant in animals and vegetables. It may be procured by heating black oxide of manganese, red oxide of lead, red oxide of mercury, nitrate of potassa (nitre), or chlorate of potassa. The latter substance gives the purest oxygen. Its compounds, when not possessing acid properties, are termed **OXIDES**, and the word **OXIDATION** is employed to express the union of a substance with oxygen. When it combines with a substance in several different proportions, the compound is termed a **PROTOXIDE** or first oxide, which contains the smallest proportion of oxygen. The second is **DEUTOXIDE** or **BIN OXIDE**, and so on. The compound containing the greatest proportion of oxygen is called **PEROXIDE**. Oxygen is the most abundant substance in nature, and there are few chemical actions either in nature or art, in which it is not engaged. Indeed, a very great part of the science of chemistry consists in an account of the relations of oxygen to other bodies. This substance has never been procured in any other than the gaseous state when uncombined. It has not been reduced to the liquid state by cold or pressure, as has been done with chlorine, carbonic acid, and some other gases.

123. *Carbonic Acid Gas in the Air.* Besides the oxygen and nitrogen, which form the chief part of atmospheric air, there are small quantities of other matters always present. Take a little lime-water (made by agitating quick-lime in powder with a quantity of water, and decanting the clear liquid at the top after the undissolved powder has subsided), place it in a saucer, so as to present an extensive surface of the liquid to the air, and examine it after a few hours; it will be found that a thin white film of hard matter has formed on the surface. This is owing to the presence of carbonic acid, which has combined with the lime in the lime-water and formed a substance (carbonate of lime) which water cannot dissolve. If this thin crust be broken, it will sink, and another will soon be formed in its place. In this manner, by removing each film as it is formed, and exposing a fresh surface of the lime-water to the air, a new crust of carbonate of lime would be formed as long as any lime remains dissolved in the water; while the lime would gradually pass from the liquid state, in union with water, to the solid state, in union with carbonic acid. Lime-water is one of the tests for carbonic acid, that is, one of the substances by which we discover if carbonic acid be present in any gas undergoing examination; for a white crust is produced on the surface of lime-water whenever it meets with any carbonic acid gas: or, if agitated with carbonic acid, the lime-water will become turbid, the white and insoluble carbonate of lime being diffused through the liquid.

124. Carbonic acid is also known by the names—

fixed air, aerial acid, mephitic acid, cretaceous acid. It is the choke-damp of old mines, pits, wells, and brewers' vats. It consists of carbon (charcoal) and oxygen; 22 parts by weight of carbonic acid contain 6 of carbon and 16 of oxygen. It is transparent and colourless like air; but it cannot support combustion or respiration, a burning body being instantly extinguished, and an animal suffocated if immersed in it. It is a heavy gas, being about one-half heavier than common air. Its specific gravity is 1.527, and 100 cubic inches weigh 47.26 grains. It may be formed synthetically by burning carbon in oxygen gas; but is generally procured by the action of muriatic acid on chalk or marble in fragments, when the gas is disengaged with effervescence, and may be collected like any other gas at the pneumatic trough. It exists very abundantly in nature, in chalk, marble, limestone, coral, and in the shells of marine animals, all of which consist chiefly of this substance in union with lime. Being in them fixed in the solid state, hence the name "fixed air." It is absorbed into the liquid state by water, which, when newly boiled and cooled, can dissolve (absorb) a quantity of carbonic acid gas equal to its own bulk. It is formed and poured into the atmosphere by many operations going on at the earth's surface, as combustion, decomposition of organic bodies. Its compounds with earthy matters are called CARBONATES. Carbonic acid may be separated from any gas containing it by lime-water, or a solution of caustic potash; and if this operation be performed in a graduated tube over water, the ascent of the liquid will indicate the quantity of this gas present. 125. The proportion of this gas in the air varies

slightly at different times, even in the same day. M. Theodore Saussure found that in summer gas is more abundant in the air than in winter; that the proportion is greater at night than in the day, and in dull cloudy weather than in sunshine; and that it is in less proportion at a plentiful fall of rain. These differences are probably owing to the effect of vegetables on the atmosphere, which varies according to the season, the intensity of the solar light, and to the fact that water possesses the power of absorbing a considerable quantity of this gas.

126. The usual proportion of carbonic acid in air will be seen in the table in page 76. It is invariably present, and has been found by M. Saussure at the top of Mont Blanc, 16,000 feet above the level of the sea. It is generally supposed to be about 1-1000th of the weight of the atmosphere, but M. Theodore Saussure estimates its quantity rather less.

3. *Watery Vapour in the Air.*

127. Every one knows that the clouds consist of watery vapour in a particular form, and that therefore there is much watery vapour in the air in cloudy weather. But there is watery vapour in the clearest atmosphere; in the driest weather there is always some moisture in the air, although we do not see it when in small quantities (90). If fragments of caustic potash (potassa fusa) be exposed to the air for some time, they will become softened, and liquid, in consequence of the moisture which they absorb from the air. This substance has a very great affinity for water, and also

and unites with it whenever they meet, but it may be kept for a very long time quite dry in a well-corked bottle, for the limited quantity of moisture mixed with the air in the bottle is insufficient to moisten the potash. In the open air, however, where it meets with as much moisture as is sufficient to render it liquid, this effect soon takes place; and, if weighed when liquid, it would be found to have increased much in weight. If the potash thus melted be heated strongly, the water may be boiled off, when the potash will be found in its former condition, dry, hard, and solid, and again ready to attract moisture whenever it meets with any. Common pearl-ash (subcarbonate of potash); or the substance called chloride of calcium, may be used instead; a similar effect will be produced. A quantity of strong sulphuric acid (oil of vitriol) will absorb from the atmosphere about a third of its weight of watery vapour in the course of twenty-four hours. These are a few of the methods by which it can be ascertained that, *in the driest weather*, there is always some watery vapour present in the atmosphere.

128. The chief cause of the presence of watery vapour in the air is the influence of heat, which, acting upon the water of all the lakes, seas, and rivers in the world, is continually infusing the repulsive principle into them, and converting part of their surface-water into vapour; even in the coldest weather this is going on to a greater or less extent. It will be seen also, under the head “Changes effected on the Air,” that there are many chemical processes going on which add watery vapour to the atmosphere. The watery vapour is the most variable

in proportion of the different ingredients of the air; which arises from the frequent variations in the temperature of the earth and atmosphere. The proportion which the watery vapour bears in general to the other ingredients of the air is about 1-100th;—see the table in page 76. The following table shows the proportion of watery vapour which can exist in a space of 100 cubic inches at the surface of the earth, at the temperatures of 32°, 50°, and 60° Fah.

32°	0.137 grains.
50°	0.247
60°	0.339

There may be less at the temperature—more will not remain in the state of vapour, but will be condensed. It is heat alone which sustains the moisture in the aerial state, not the attraction of the air, as was at one time supposed.

129. Various **HYGROMETERS** have been devised for ascertaining the quantity of moisture in the air, and indicating any changes in this respect. Hair and whalebone have been employed, contracting when the air is dry, and dilating when it is moist, an index being attached which turns and points to a scale. The most correct is Daniell's, in which the surface of a glass bulb is cooled until it condenses the surrounding vapour, which is deposited as dew upon the bulb. By noting the temperature of the bulb when the moisture is first seen on its surface, and the temperature of the atmosphere at the time, data are procured for telling with great precision the *quantity of watery vapour in any given space*, and the probability of rain or snow falling soon.

This is the DEW-POINT HYGROMETER, and in some form or other, is that always employed now.

4. *Other Matters in the Air.*

130. The four substances already mentioned, namely, oxygen, nitrogen, carbonic acid gas, and watery vapour, are *always* present in the atmosphere, always (with the exception of the watery vapour and the carbonic acid gas, the latter of which seldom varies much) in the same proportion, and they can always be detected by chemical analysis.

131. But when we consider how many gases and vapours of various kinds are constantly being formed at the surface of the earth, it is clear that there must be many other matters in the air, although chemical investigation has not been able to detect them. They may elude the search of chemistry, because we have not any tests to indicate their presence, or because they bear such a small proportion to the whole mass of air. In air near the ocean, a little muriatic acid (marine acid) has been sometimes detected, and a foreign chemist on one occasion found some nitric acid (aqua fortis) in some rain-water which had fallen after lightning; see par. 21. Being the medium of all smells, the air must contain the odóiferous particles emanating from all bodies which have any peculiar odour. In large towns where great quantities of coal are burned, the air will contain many impurities derived from the combustion of the coal, as sulphurous acid, sulphuric acid, sulphate of ammonia, and charcoal in suspension in the state of a fine powder, which forms a great part of smoke. But all these become soon diffused among the general atmosphere, and are lost. Even near

volcanoes, where very large quantities of similar vapours are poured into the air, the equilibrium is soon restored, and no trace remains of these impurities.

132. It has been conjectured that the air contains diffused through it gaseous particles from every substance with which it is in contact. But this has been shown by Mr Faraday to be very improbable, many substances, such as earthy matters and metals, having vapours of such weak elastic force, that their particles are unable, at the temperature prevalent at the warmest parts of the earth's surface, to overcome the attractions of gravitation and cohesion and assume the gaseous form. He found that quicksilver gave off a very small quantity of vapour at temperatures between 60° and 80° Fah., but none below 60° , and this is the most volatile of the substances of a metallic nature, or having a metallic basis.

133. Air is always found to be of the same chemical composition. In every country, in Britain, France, or Spain, in the flat and moist plains of Egypt, on the parched coast of Africa, in low valleys, and at the greatest elevation which has been attained by travellers, on the top of Mont Blanc, or at the Peak of Teneriffe, nearly 12,000 feet above the level of the sea, in town and country, in manufactories, in the most close and ill-aired places, those deemed the most unhealthy, and those reckoned the most salubrious, above stagnant water and marshes, during the most wholesome weather, or during the prevalence of the most virulent epidemics, as cholera or typhus fever, the air is always found the same; that is, those ingredients which alter its character cannot be detected by chemical analysis. Seguin examined

the unwholesome air in an hospital filled with patients labouring under some infectious disease, and which had an exceedingly strong and offensive odour, and could not detect any difference between it and the fresh air of the country, so extremely subtle are those ingredients which communicate to the atmosphere any deleterious properties. Any other matters besides the four substances already mentioned, must be present in extremely small quantities.

134. When the composition of the air was discovered, and it was found that it is the oxygen which it contains to which it owes its property of supporting animal life, it was imagined that the varying qualities of the air, with respect to its wholesomeness, depend on varying proportions of oxygen, that by ascertaining the quantity of this gas in the air at any time or place, we should be able to form an estimate of its salubrity, and even that by adding oxygen an artificial atmosphere might be formed which would be free from any unwholesome qualities. It was not surprising that, seeing a little of the nature of the air which we breathe and its use in respiration, some of the philosophers of those days should have jumped to the conclusion that the wholesomeness of the atmosphere depends upon the quantity of oxygen which it contains. Hence arose the **EUBIOMETER**, an instrument for measuring the quantity of oxygen in the air, or, as was then imagined, the purity of the air. This idea received some confirmation from the differences in the proportion of oxygen in air found by the earlier chemists who examined its composition; but this is now known to have arisen from their comparatively inaccurate methods of examination; now, it is proved that the

proportion of oxygen is the same in all times and all places.

135. The principle on which the endiometer depends, is the abstraction of oxygen by means of a substance which has an affinity for it, and if operation be carried on in graduated vessels, we then judge of the quantity of oxygen which has been removed. The matters formerly used for this purpose were those mentioned in paragraphs 111.

The method of ascertaining the proportion of oxygen in air, now always resorted to, is by hydrogen gas, which, when mixed with air, and kindled by an electric spark, removes all the oxygen, leaving the whole of the nitrogen. This will be explained afterwards, and the method of performing the experiment described.—See *Endiometer, Ure's*.

VII. CHANGES EFFECTED ON THE AIR BY VARIOUS CHEMICAL OPERATIONS IN WHICH IT IS CONCERNED.

136. The air is continually undergoing various changes, which alter, or have a tendency to alter, its nature and chemical composition. From its presence every where about the surface of the globe, it is necessarily exposed to the chemical action of various bodies which can have any effect upon it; and the most important changes are effected on the bodies to which it acts, while it itself becomes changed at the same time. The most important of those operations which effect a change on the atmosphere are, the respiration of animals; the respiration of plants (the action between the matter of the plant and the atmosphere which goes on in the leaves); the germination

sprouting of plants; the decomposition of animate beings (animals and vegetables), including the chemical operations of fermentation and putrefaction; and lastly, the process of combustion or burning;—all going on so extensively at the surface of the earth. The air is also more or less modified by its action on rocks and soils; and by water, which absorbs it, taking up its various ingredients in unequal proportions.

1. *Change produced on the Air by the Respiration of Animals.*

137. We make use of the air many thousand times every day, by taking it into the lungs; and it need hardly be mentioned, that either what we inhale by the lungs does not entirely remain in the body, adding to its weight, or a corresponding quantity of some other gas is given out in its place; for, immediately after the *inspiration* of a quantity of air, a quantity of gas of some kind is expelled from the lungs, by what is called an *expiration*, and the bulk of the air inspired is nearly the same as of that expired. The term *respiration* is applied to a complete act of breathing, consisting of an inspiration and an expiration.

138. Now, we cannot suppose that the gas which leaves the lungs is exactly the same as that which entered; it is likely that, after being used in the lungs, some change will have been effected on the air; or, perhaps, the air taken in has been entirely or in part retained, and a different gas expelled.

139. The gas expelled from the lungs, in general, like the air taken into the lungs, is invisible in small quantities. Yet, sometimes it does become visible,

more particularly in cold weather, when the expired gas assumes an appearance like that of steam issuing from the spout of a boiler. This is well seen in the breathing of horses on a frosty day; two large clouds of opaque gas (vapour) are seen issuing from the nostrils, and even the breath from our own lungs seen very distinctly in cold weather. The appearance of this expired air might lead us to suspect that it contains or consists of watery vapour, it bears so strong a resemblance to steam; upon trying the experiment, it will be found that this inference is correct. Breathe into a cold glass vessel which is quite clear; the sides of the tumbler will instantly lose their clearness and transparency, and upon breathing two or three times into the tumbler, it will be then found to be bedewed with moisture. Now, although the air taken in contained a little watery vapour (109), it is clear that the air given out contains a great deal more; hence, by this simple experiment, we ascertained that *one effect of respiration is to add a quantity of watery vapour to the air.*

140. The quantity of watery vapour given off by respiration has been variously estimated—by Menzies at 2880 grains in 24 hours—by Thomson at 900 grains—by Abernethy at 4320 grains in 24 hours—by others 3 grains every minute. The latter has been adopted as probably the most correct.

141. Another experiment, almost equally simple as that described in par. 139 by which we ascertained the presence of watery vapour in the air expelled from the lungs, will indicate another more marked difference between the air taken in by the lungs and that given out. Let a little li-

water be put in a wine-glass or tumbler ; the lime-water, when pure, is remarkably clear and pellucid. Blow into the liquid by means of a tube, so that the air expelled from the lungs passes through the lime-water. In the course of half a minute, the liquid will begin to turn white and opaque, and if the breathing through it be continued for a short time longer, the liquid will have completely lost its colourless and limpid character, be perfectly white and opaque, and somewhat thick and muddy. We saw in par. 123 that lime-water is used to detect the presence of carbonic acid gas, forming with it a white solid which water cannot dissolve. This has taken place in the present instance—by breathing through the lime-water, a white insoluble powder has become diffused through it. Now, if lime-water be shaken with common air in a bottle, it would be found, that to produce an equal degree of muddiness in the liquid (that is, an equal quantity of the white solid), a much larger quantity of common air than of air breathed out from the lungs would be required ; hence we infer that *another effect of respiration is to add a quantity of carbonic acid gas to the air.* If the air expired be more minutely examined, it will be found that it contains about the same proportion of nitrogen as that taken in, but a less proportion of oxygen, the place of the oxygen wanting being supplied by carbonic acid. Thus, another effect of respiration is to remove some of the oxygen of the air. It is supposed that a man of average size consumes about 26·6 cubic inches of oxygen every minute, substituting an equal bulk of carbonic acid. Similar effects are produced by the respiration of animals.

2. *Change produced on the Air by the Respiration of Plants.*

142. This is a subject on which very conflicting opinions have been entertained. There is no doubt, from the experiments of various philosophers, that at times the leaves of plants produce the same effect on the atmosphere as the lungs of animals, namely, cause an increase in the quantity of carbonic acid, by giving out carbon in union with the oxygen of the air, which is thus converted into this gas; and it has been also established that at certain times the leaves of plants produce a very opposite effect, namely, that they decompose the carbonic acid of the air, retain the carbon, and give out the oxygen, thus *adding to the quantity of the oxygen in the air*. It has not yet been precisely ascertained which of these goes on to the greater extent, but the general opinion at present is, that the gross result of the action of plants on the atmosphere is—the *depriving it of carbonic acid, retaining the carbon, and giving out the oxygen—thus increasing the quantity of free oxygen in the air*.

3. *Change produced on the Air by the Germination of Plants.*

143. This is better understood than the last; it is now well known that in the sprouting of plants part of the oxygen of the air is turned into carbonic acid, so that *the effect of germination is the addition of carbonic acid to the air*.

4. *Change produced on the Air by Fermentation, &c.*

144. During that chemical process which goes on when vegetable matters turn sweet, called the *saccharine fermentation* (exemplified in the ripening of fruits), carbonic acid gas is added to the atmosphere. The same effect is produced when vegetable matters become converted into spirituous liquors, an operation called the *vinous fermentation*, or when they are converted into vinegar, which is called the *acetous fermentation*:—and, during the *putrefactive fermentation* (the spontaneous decomposition of vegetable substances), it is chiefly carbonic acid gas and watery vapour which are added to the air. In the case of the decomposition of animal matters also, these substances (carbonic acid and watery vapour) are the compounds formed in greatest quantity. In these cases, the oxygen of the carbonic acid is, in some, derived from the air, in some, from the animal or vegetable substance which is decomposed. *Hence, then, all kinds of fermentation and decomposition of organic (71) bodies increase the quantity of carbonic acid in the air, and some add to the watery vapour in the air.*

5. *Changes produced on the Air during Combustion or Burning.*

145. It has been already mentioned, that by burning several bodies in a limited quantity of air, the oxygen would be altered, but the nitrogen left. In general, the combustible body consists chiefly of charcoal, as wood, coal, tallow, &c. There are other substances which undergo combustion, as sulphur, phosphorus, hydrogen: but in most cases, charcoal

is the combustible material. Place a jar over a common candle while burning, and let it remain over it for a short time ; or place a burning candle in a jar. A candle is a substance, the combustible material of which contains a considerable quantity of charcoal. The candle will soon be extinguished. Remove the candle from the jar, with as little agitation of the air in the jar as possible ; and pour into the jar a little lime-water. If the jar be a long one, and the candle have burnt in it for some time, the lime-water will be rendered muddy, as soon as (or even before) it has reached the bottom : but at all events, on shaking the jar so as to bring the liquid in contact with as much of the gas as possible, the lime-water will be rendered opaque and of a whitish colour, in the same way as in the former experiments with lime-water. It will be found, that by the air in the jar, after the burning of the candle, a much greater quantity of the carbonate of lime (123) will be formed than with an equal quantity of common air which had not been used for the combustion of any substance ; hence, in cases where charcoal forms or is contained in the burning body, (and, in most cases, this forms the principal part of such substances), *the process of combustion adds to the quantity of carbonic acid gas in the air, the quantity of oxygen being proportionally diminished.*

146. But there are many other combustible bodies besides charcoal. What change is effected on the air when phosphorus, sulphur, hydrogen, &c., burn ? All combine with oxygen of the air, rendering it unfit to support combustion ; but of the compounds thus formed we need not attend to any at present

but that produced when hydrogen burns, for the rest exist in such minute quantity in the air that their presence cannot be detected, and hence they do not fall to be considered under atmospheric air. But hydrogen exists in most combustible bodies, as coal, or wood, so that the compound, which, when made to burn, it forms by uniting with the oxygen of the air, must exist more abundantly in the atmosphere. This compound is *watery vapour*. The following very simple but not less curious experiment will afford a demonstration of this.

147. If a spirit-lamp, or even a common candle, burning without much smoke, be placed while burning below a large cold glass jar, which is clear and shining, almost immediately the sides of the vessel will become dull and opaque, losing their shining lustre, and in the course of a minute or two, the vessel will be bedewed with moisture, a great number of very small drops of water covering its sides. These substances, the tallow of the candle, and the spirit of the spirit-lamp, contain hydrogen; and, *in all cases of the combustion of bodies which contain any hydrogen, a quantity of watery vapour is added to the atmosphere, the free oxygen being diminished in proportion.*

VIII. USES OF THE AIR.

148. There is no body in nature that is so essential to the existence of man, and few that contribute to his welfare in such a variety of ways, as the atmosphere. The atmosphere affords the material for the respiration, or breathing of plants and animals, and so necessary is it to the existence of the latter, that we make use of it about twenty-five thousand

times every day; and being deprived of it for even a very few minutes proves fatal; it is by means of an ingredient of the atmosphere that we procure artificial light and heat, without the means of producing which mankind could never have emerged from the savage state; the atmosphere is the medium by which the heat of the sun, which falls so unequally on different parts of the earth's surface, is diffused over the different regions, moderated in the burning climate of the torrid zone, and conveyed north and south to enliven the desolate countries around the poles; the air, by its motions, propels ships along their liquid path, thus giving rise to commerce and intercourse between nations; the atmosphere, by its power of reflecting light and dispersing it about in all directions, enables us to see objects though they are not illuminated by the *direct* light of the sun; and by its property of conveying sound, raises man above the lower creation, endows him with the pleasures and sympathies of a social being, and enables him, by co-operation, to rear those stupendous monuments of human industry and knowledge, which the arts and manufactures, in their present advanced condition, present to our view on every side. Of these, only the first two come strictly within the province of chemistry.

1. *Use of the Oxygen of the Air.*

149. The oxygen of the air may be considered the essential, the active part of the air, the part which *does* every thing. It is the oxygen chiefly which is engaged and becomes altered in all those chemical operations in which the air is concerned; the nitrogen seldom undergoes any alteration, acting

chiefly as a damper, moderating the action of the oxygen, and preventing it from *doing too much*.

150. In RESPIRATION the air meets the blood in the lungs; and part of the oxygen is converted into carbonic acid by combining with carbon (charcoal) in the lungs; or, in the lungs, it is absorbed and retained by the blood, and carbonic acid is given off; or, both take place, so much oxygen being absorbed, and so much being given off in the state of carbonic acid. It is not certain which of these is the true theory of respiration, but it is certain that carbon (in union with oxygen) is expelled from the lungs during respiration. The amount of *ascertained facts* regarding the effect produced on the air during respiration may be seen in the following extract from Dr Bostock's Physiology.

151. " Air which has been respired loses a part of its oxygen; the quantity varies considerably, not only in the different kinds of animals but in different animals of the same species, and even in the same animal at different times, according to the operation of certain external agents, and of certain states of the constitution and functions. Upon an average we may assume that a man, under ordinary circumstances, consumes about 45,000 cubic inches, or nearly 15,500 grains of oxygen in 24 hours. 2. A quantity of carbonic acid is produced, the amount of which varies very much according to circumstances, both external and internal; its quantity depends, to a certain extent, upon the quantity of oxygen consumed, but the two are not in exact proportion to each other; in a great majority of cases the quantity of carbonic acid produced will be found to be less than that of the oxygen consumed, so that there

will be a surplus quantity of oxygen more than is necessary for the production of the carbonic acid. In consequence of the variations which take place in the amount of the carbonic acid produced, it appears almost impossible to fix upon any number which may indicate the average quantity ; but it may be stated to be somewhere about 40,000 cubic inches in 24 hours. This will weigh 18,600 grs., or nearly 3 lbs., and will contain 5208 grs. of charcoal and 13,392 grs. of oxygen, which will be 2100 grs. less than the quantity of oxygen consumed. 3. The volume of the air is diminished by respiration, but this, like the changes mentioned above, varies so much at different times, that it is almost impossible to form any statement of the quantity ; perhaps we may assume that air, which has been once respired, is diminished by about 1-80th of its bulk. 4. It appears probable that nitrogen is both absorbed by the lungs and exhaled from them ; but the two processes of absorption and exhalation differ very much, both in their absolute quantity, and in the relation which they bear to each other, so that the proportion of nitrogen in the air is sometimes diminished by respiration, is occasionally increased, and frequently remains without alteration. 5. A quantity of aqueous vapour is discharged from the lungs, mixed with or diffused through the air of expiration ; but we have not sufficient data from which to decide upon its amount, and it is probable that the quantity varies considerably in the different conditions of the system, and the different situations in which the body is placed."

152. Thus the main use of respiration is to expel a superfluous quantity of carbon from the body, *and*

the oxygen of the air effects this by uniting with the carbon, and thus converting it into a gaseous substance (carbonic acid gas), in which form it is more easily got rid of. Some late experiments by Dr Edwards would seem to indicate that *all* the oxygen taken in is absorbed, and he found in some cases that the expired carbonic acid is in the lungs, ready to be given off, independently of oxygen inspired at the time; but this does not invalidate the above natural conclusion, that the oxygen may serve to convert carbon in the blood into carbonic acid, although this gas may not be formed from the oxygen taken in during the inspiration *immediately preceding* the expiration by which it is given off. From the above estimate, it appears that about 11 ounces avoidr. of carbon (charcoal) are given off daily from the lungs.

153. The number of respirations in a minute are supposed to be about 20. The quantity of air taken in at each respiration has been estimated by Menzies, and others, at 40 cubic inches; by Dalton at 30 cubic inches; by Herbst at 20; by Jurine at 20; by Kite, and Davy in one estimate, at 17; by Allen and Pepys at $16\frac{1}{2}$; by Davy at 13; by Abernethy at 12 cubic inches. Perhaps 20 cubic inches, as an average, may be not far from the truth. This gives 400 cubic inches of air taken into the lungs every minute—13 cubic feet and 1536 cubic inches every hour—333 cubic feet in the 24 hours. Of this, one-fifth, 66 cubic feet, or 114,048 cubic inches, consists of oxygen. If we suppose, with Dr Bostock, that 45,000 cubic inches of oxygen are consumed, this is nearly in the proportion of 3-8ths of the oxygen taken in; in cubic feet, about 26, as the quantity of

oxygen *consumed* daily. And if we adhere to the same estimate as to the quantity of carbonic acid produced, 40,000 cubic inches, this gives 23 cubic feet daily, or nearly a cubic foot of carbonic acid added to the atmosphere every hour. The following table shows the estimates of various chemists on these points:—

	Oxygen consumed in 24 hours.		Carbonic acid evolved in 24 hours.	
	<i>Cubic inches.</i>	<i>Grains.</i>	<i>Cubic inches.</i>	<i>Grains.</i>
Menzies . . .	51,840	17,625		
Lavoisier . . .	46,048	15,541		
Davy	45,504	15,751	31,680	17,812
Allen and Pepys	39,600	13,464	39,600	18,612

It is considered by many physiologists that the oxygen consumed is replaced by an exactly equal bulk of carbonic acid. The above estimates are tolerably near each other, as to the quantity of oxygen consumed. But some have considered that it is not likely that so large a quantity of carbonic acid (18,612 grains, and containing about 11 ounces avoirdupois of carbon) should be evolved daily from the lungs.

154. Such being the use of the air in respiration we can easily understand how life is instantly destroyed, if an animal be placed in a situation where it cannot procure oxygen—free oxygen, ready to combine with the carbon of the blood. This takes place when an animal is immersed in nitrogen, or in any gas which either contains no oxygen, or the oxygen with very much altered properties, and not in a state to combine with the carbon in the lungs in consequence of being already chemically united with some substance. It has not been precisely ascertained what proportion of oxygen air must con-

tain to render it fit for respiration. It is found, that animals enclosed in a limited quantity of air die before the whole of the oxygen has been consumed, but this is attributed to the carbonic acid which is present, as will be seen in the next paragraphs. Lavoisier enclosed a guinea-pig in a limited portion of air, and by means of caustic potash removed the carbonic acid as fast as it was formed; he found that the animal could live, apparently without any uneasiness, in air that contained only $6\frac{1}{2}$ per cent. of oxygen, and that when there was a still smaller proportion of this gas present, the only apparent effect was a slight drowsiness. As the guinea-pig is an animal of the same general structure, as far as regards the organs of respiration, as man, it has been supposed, that air with an equally small proportion of oxygen might support human existence.

155. It is from the diminution in the proportion of free oxygen, and the presence of carbonic acid, that air which has been frequently breathed becomes totally unfit for the support of respiration, and hence the necessity for efficient ventilation, that there may be a free circulation of air, in apartments where a number of people are assembled, in order that, by frequently renewing the air, they may not be obliged to breathe the same air over and over again, which, it is well known, is attended with very deleterious effects.

156. Two bad effects result from the same portion of air being breathed more than once. 1. The quantity of free oxygen in the air is diminished each time it is inspired, till at last the air is nearly exhausted of its free oxygen, the matter required;—there is thus a negative injury sustained from the want of

oxygen:—2. There is a positive injury inflicted on air frequently respired, for there is a quantity of carbonic acid produced by each respiration, which of course increases the oftener the same portion of air is used; *and this carbonic acid acts as a potent narcotic poison, destroying its victim by the most certain though insidious means, gradually stupifying the individual and inducing a state of torpor, which if the breathing of the carbonic acid be continued for some time, would end in total insensibility and death.* Carbonic acid, unmixed with any other gas *cannot be respired at all*; whenever a draught of this gas comes in contact with the glottis (the opening leading to the windpipe), this aperture becomes quite closed up, so that none of the carbonic acid gas can be taken into the lungs at all: and Dr Humphry Davy found that air containing so much as three-fifths of its bulk of this gas cannot be respired. *But when the proportion of carbonic acid in air is reduced to three-tenths, it is admitted into the lungs, and after being breathed for a minute causes a slight giddiness and tendency to sleep. Hence we may perceive the absolute necessity of continual supplies of fresh air to the lungs, for the effect of breathing frequently the same portion of air will be to induce gradually a drowsiness, which will necessarily render the individual insensible to his danger, and incapable of removing: this will be superseded by sleep, which, if he be not roused and if he continue inhaling the carbonic acid, will pass gradually into a sleep from which he never can awake.*

157. There is a fatal instance of this, of which almost every one has heard—in which a great num

ber of persons lost their lives, from being compelled to breathe the same air over and over again—the black hole of Calcutta. A hundred and forty-six persons were confined for a whole night in a very small room, with a small window, and no contrivance for renewing the air, and of these unfortunate individuals, only twenty-three survived. By the breathing of so great a number of persons in so small a quantity of air, it soon became highly charged with carbonic acid, the matter into which the oxygen was converted, and being taken into the lungs, acted as a poison, gradually rendered them insensible, and accelerated their destruction.

158. There are two remarkable instances in nature of a corrupted state of the atmosphere, by which it is unable to support animal life—the grotto del cano (grotto of the dog) in Italy, and the Valley of Death in the island of Java—both depending on the presence of carbonic acid in the atmosphere in unusually large proportion; the latter has been described by Mr Loudon in No. 23 of the Edinburgh Philosophical Journal, from which the following extracts are made.

“*Balor, 3d July, 1830.*—This evening, while walking round the village with the Patteh (native chief), he told me that there is a valley only three miles from Balor, that no person could approach without forfeiting their lives, and that the skeletons of human beings, and all sorts of beasts and birds, covered the bottom of the valley. We took with us two dogs and some fowls, to try experiments in this poisonous hollow. When within a few yards of the valley we experienced a strong nauseous suffocating smell, but, on coming close to the edge, this disagree-

able smell left us. We were now all lost in astonishment at the awful scene before us. The valley appeared to be about half a mile in circumference oval, and the depth from 30 to 35 feet, the bottom quite flat,—no vegetation,—some very large, in appearance, river-stones, and the whole covered with the skeletons of human beings, tygers, pigs, deer peacocks, and all sorts of birds. We could not perceive any vapour or any opening in the ground, which last appeared to be of a hard sandy substance. The sides of the valley from the top to the bottom are covered with trees, shrubs, &c. It was now proposed by one of the party to enter the valley; but at the spot where we were, this was difficult, at least for me, as one false step would have brought us to eternity, as no assistance could be given. We lighted our cigars, and, with the assistance of a bamboo, we went down within 18 feet of the bottom. Here we did not experience any difficulty in breathing, but an offensive nauseous smell annoyed us. We now fastened a dog to the end of a bamboo, 18 feet long, and sent him in; we had our watches in our hands, and in 14 seconds he fell on his back, did not move his limbs or look around, but continued to breathe 18 minutes. We then sent in another, or rather he got loose from the bamboo, but walked in to where the other dog was lying: he then stood quite still, and in 10 seconds he fell on his face, and never moved his limbs afterwards: he continued to breathe for 7 minutes. We now tried a fowl, which died in $1\frac{1}{2}$ minute. We threw in another, which died before touching the ground. During these experiments we experienced a heavy shower of rain; but we were so interested by the awful scene before

us, that we did not care for getting wet. On the opposite side, near a large stone, was the skeleton of a human being, who must have perished on his back, with the right arm under the head: from being exposed to the weather, the bones were bleached as white as ivory. I was anxious to procure this skeleton, but any attempt to get at it would have been madness." "The human skeletons are supposed to have been rebels, who had been pursued from the main road, and taken refuge in the different valleys, as a wanderer cannot know his danger till he is in the valley, and when once there, one has not the power or presence of mind to return."

159. It does not seem that any attempts were made to collect some of the air in the valley for examination, but there is every reason to believe, that it consists of, or contains a large proportion of, carbonic acid, a gas which is known to be abundant in volcanic countries, while the effects on the animals sent in to the valley resemble those which would be produced in an atmosphere of this gas. Carbonic acid gas is very heavy, and hence readily accumulates in any low situation where it may be poured into the atmosphere. In the present case, and in the Grotto del Cane (a cave in which similar phenomena are observed in the strata of air next the ground), it may be supposed, that the carbonic acid gas is produced in the interior of the earth by some volcanic actions, which it is known are continually going on at no great distance, and that by fissures in the ground it passes through to the surface, where, from being surrounded by the sides of the valley, and thus excluded from the action of the

winds, it accumulates, and mixes very slowly with the general mass of the atmosphere.

160. In FERMENTATION, and all the spontaneous chemical changes which dead organic substances pass through, the oxygen of the air, by turning carbon into carbonic acid, and the hydrogen into watery vapour, plays an important part in bringing about the change; and the putrefaction of a number of animal and vegetable substances would proceed with comparative slowness, if they were carefully excluded from the access of air.

161. In GERMINATION, the main use of the presence of which is essential, seems to be to remove carbon from the seed by furnishing oxygen which converts the carbon into carbonic acid; and hence germination does not go on if the seed is buried too deep in the soil, where it would not have access to a free supply of air. Carbon is a substance of a very antiputrescent nature, and thus assists in preserving the seed for a great length of time. When a portion of the carbon is removed and some water is absorbed, the matter of the seed becomes liquid, and of a saccharine nature, appropriate food for the young plant.

162. In the RESPIRATION or breathing of plants, the oxygen, at times, plays the same part as in the respiration of animals, namely, removing carbon from the plant.

163. In COMBUSTION or burning, it is the oxygen of the air alone which is used, the nitrogen remaining unaltered. It is in consequence of a chemical attraction subsisting between the burning body and the oxygen of the air, that the burning goes on, and

oxygen undergoing a change from being chemically united with the combustible body, and being no longer able to support the combustion of that substance, while, at the same time, the combustible body is altered from being united to oxygen. Hence the reason why a lighted candle is immediately extinguished if placed in a quantity of air from which the oxygen has been withdrawn (nitrogen—94); or in almost any situation where it cannot procure free oxygen, ready to combine with the combustible body. Perhaps next to its use in the support of animal and vegetable life, this is one of the most important of the purposes which are served by our atmosphere, and this depends entirely upon the oxygen which it contains; all the other ingredients in the atmosphere retard the process of combustion.

164. We have seen (153), that in respiration the whole of the oxygen in a portion of air inspired is not used, and (154), that a less proportion of oxygen might serve; but that the presence of carbonic acid in too large quantities is injurious to the animal system: it is the same with combustion. The burning of a candle could go on with a smaller proportion of oxygen than that usually in the air, but the carbonic acid formed, if not removed, actually checks the combustion, and hence a candle, burning in a limited quantity of air, is extinguished long before the whole of the free oxygen is consumed; the carbonic acid which it produces exerting a certain influence in putting a stop to the combustion.

165. Here we may notice the singular analogy between these two operations, combustion and respiration, so opposite in many respects. It is certainly curious, that in respiration, a process so essential to

the existence of animal life, carried on unremittingly from the dawn of existence to its close, and with a so calm and moderate in its mode of action, the chemical changes which go on should be so similar in their nature and effects to that which goes on in combustion,—a process of so wild, violent, and irregular a nature, and generally regarded as the emblem of destruction. We could hardly have imagined, on considering the characters of these two operations, that they are *performed by the same materials, brought about by the same general forces and produce the same changes on the material engaged*. This analogy affords a striking example of the harmony of adjustment, simplicity of method and economy of material, by which the great operations of nature are brought about. Respiration and combustion, being so similar in their nature, *on material, oxygen, serves for both*, and this active substance is the leading agent, at the same time, in a thousand other operations essential to animal existence. Thus, a variety of important changes, different in their characters and in the ends to be fulfilled, are all brought about by one universal agent and it is supplied to all bodies which require it, by giving it the gaseous form, and making it encircle the earth on all sides.

166. The analogy between combustion and respiration is well illustrated by this—that *each renders the air unfit for the other*: a quantity of air which has been expelled from the lungs will hardly support the combustion of a candle, and if the same portion of air be breathed more than once, it will extinguish immediately the flame of a candle; while on the other hand, air in which a fire, or several

lamps, or several candles, have burned for some time, will be unfit for respiration, and would almost instantly suffocate any person who would attempt to breathe it. This we would expect, as we know that combustion diminishes the quantity of free oxygen in the air, and, in most cases (145), adds carbonic acid to the air. This gas, we have seen, acts as a poison (156)—and hence the danger of sleeping in apartments where combustion is going on to any extent, and where there are not proper ventilating arrangements for removing the carbonic acid when formed. Fatal effects have been known to result from chauffers, containing burning charcoal or coke, being placed in bed-rooms : *the charcoal or coke in burning produce no smoke, and are hence sometimes thought inoffensive, but this gas (the carbonic acid) is produced, and though invisible, is not the less deadly, if allowed to accumulate in a close apartment where any person is sleeping.*

167. OXYGEN also plays an important part in those changes which take place in rocks and minerals exposed to the atmosphere, by which some are broken down and disintegrated (ground down to earth), or formed into crystalline salts. This will be alluded to in the chapter on the mineral kingdom.

2. Use of the Nitrogen of the Air.

168. In many of those operations which are carried on by means of the oxygen of the air, the nitrogen is little if at all affected, generally remaining after the conclusion of the process, unaltered in its chemical relations, and undiminished in quantity. In some of the experiments with respiration, however, it was found that part of the nitrogen

disappeared, and as nitrogen is present in such large and constant quantities in the atmosphere, and as it is an essential ingredient in the composition of animals, it has been conjectured, that the nitrogen of the air conduces to some important end in the support of animal life.

169. The effects which oxygen produces on combustion and respiration, when unmixed with any other gas (102), point out to us another and a very important purpose which the nitrogen serves. It will be seen in the paragraph just referred to, that pure oxygen causes combustion and respiration to go on too quickly, with too much energy; hence, *the nitrogen prevents combustion and respiration from going on too fast.* Did the air consist of oxygen alone, the least spark of fire would kindle the whole of the combustible materials on the surface of the globe. They would be partly reduced to ashes, and partly resolved into gaseous matters which would mix with the air, and render it unfit for the respiration of animals. But the respiration of living beings would also go on in the same hurried manner, and their lives would be speedily brought to a close; their respiration would be "fast and furious;" the circulation of the blood would be accelerated to a dangerous rapidity; our present constitutions would be speedily exhausted by the too great activity and violent exercise of the organs which would be caused by the stimulus of undiluted oxygen taken into the lungs; the high state of excitement would speedily terminate in excessive debility and death; like the candle, which in oxygen burns more brilliantly, but more rapidly, *and is sooner consumed, the flame of life would*

be more vivid, but could only endure for a few hours. The pulse of a person who breathed oxygen gas for a short time rose in a very few minutes, from sixty-four beats in a minute, so high as to give one hundred and twenty beats in the same time.—The oxygen, however, is not presented to us pure; it is mixed with a large quantity of a gas which is totally inert and passive, being perfectly harmless, and at the same time destitute of any stimulating effects; this diminishes the energy of the oxygen, and fits it for the support of animal life in that calm and moderate way, by which it is extended over the length of time now allotted to the various classes of living beings.

170. The nitrogen of the air assists in forming those native salts which contain it, as nitre (nitrate of potassa), sal-ammoniac (muriate of ammonia), and other native products of which nitrogen is an element.

3. *Use of the Carbonic Acid Gas in the Air.*

171. It is contrary to the general economy and harmony of adjustment observed in the works of nature, to suppose that the carbonic acid, although the product of several important operations, does not itself, when formed, serve some useful purpose in the economy of nature. There is no such thing as *refuse* in the works of nature—no residue to be cast away—for every thing is turned to account in some way or other. The carbonic acid in the atmosphere is one source from which plants derive their carbon; they take in the carbonic acid, retain the carbon, and give out the oxygen (142), and if we saw no other use of the carbonic acid but that of furnishing carbon for the growth of the first natural crops on

rocks or newly made soils, which do not contain any dead vegetable matter to supply carbon, and thus rendering these fit for the support of other and larger vegetables, we would have abundant reason to instance the presence of carbonic acid in the atmosphere as another example of the adjustment, economy, and reciprocal dependence, which are uniformly observed in the works of nature, whenever we are able to obtain a glimpse of her designs, or trace any of the methods which she employs. Another great end brought about partly by the carbonic acid in the air, is the decomposition of rocks, so that they become broken down into the state of earth, in the manner which will be explained afterwards when we come to consider the composition of rocks and soils, and how the latter are formed from rocks. The term "accidental" ought not to be applied to the presence of the carbonic acid in the air—it has important offices to perform as well as the oxygen, and is truly an *essential* ingredient in the composition of the air, although it may not be used in *all* the operations carried on by this multifarious agent.

4. *Use of the Watery Vapour in the Air.*

172. It is from the watery vapour in the atmosphere that all our fresh water is derived; whether furnished to us by rivers, lakes, springs, or wells, it has existed previously in the air in the state of vapour. The water supplied by the air also assists in disintegrating rocks, and bringing them to the state of earth or soil fit for the rearing of vegetables; the carbonic acid and the moisture furnished by the *air being* the chief agents which act chemically in

producing this effect. The watery vapour in the atmosphere is also of great importance to vegetables, which, during the absence of rain, and when the soil is parched, receive their supplies of water, so essential to their existence, from this source, in the form of dew.

IX. DO THE PROPORTIONS OF THE DIFFERENT INGREDIENTS OF THE AIR ALWAYS REMAIN THE SAME, OR IS THERE A GRADUAL AND PERMANENT CHANGE INDUCED BY THE VARIOUS OPERATIONS WHICH AFFECT ITS COMPOSITION?

173. Since the chemical composition of the air was first ascertained by Scheele, and determined with accuracy by succeeding chemists, it has been carefully examined from time to time, and it has been found to be identically the same in the proportion of its elements at the present day, as twenty, thirty, or forty years ago, from whatever situation the air examined may be taken. Now, since we know that the air is always becoming changed by the various processes in which it is concerned, in what way, will it be asked, does it always remain the same? Since such enormous quantities of oxygen are taken from the atmosphere by the lungs, and by burning bodies, and its place supplied by the carbonic acid and watery vapour, how is it that we do not perceive a diminution in the quantity of the oxygen, that the air does not become unfit for those operations which depend on the oxygen which it contains, and why do we not perceive an increase in the proportion of carbonic acid and watery vapour?

174. The manner in which the watery vapour is disposed of is well understood; it is condensed into water (*rain, dew, hail, hoar-frost, snow*), and thus

returned to the earth; but chemists were at a loss to account for the way in which the atmosphere is freed from the carbonic acid. Let us consider the amount of change effected on the atmosphere by one of the processes by which it is altered, selecting that of which it is most easy to make a precise calculation, namely, the change produced on the air by the respiration of the animal, MAN.

175. We have seen (153) that there are about 23 cubic feet of carbonic acid gas expelled daily from the lungs of an average-sized man. Making due allowances for the small size of the chest in females and in young persons, we may take (and perhaps the estimate is rather high) 13 cubic feet as the average quantity of carbonic acid added to the air in a day by each of the human race. A hundred cubic inches of carbonic acid gas weigh about forty-seven grains,* and there are seventeen hundred and twenty-eight cubic inches in a cubic foot; therefore, to state the proportions by weight, each individual adds about 10,500 grains (about a pound and a half avoirdupois) of carbonic acid gas daily to the atmosphere: there are about a thousand millions of persons on the globe—hence *the whole human race add daily to the air fifteen hundred millions of pounds of carbonic acid*; and in twenty years 10,950 thousands of millions of pounds weight of this gas, (10,950,000,000,000); which, stated in tons, comes to forty-eight hundred millions of tons

* The proportions, estimated by bulk, given above for the quantity of carbonic acid expired from the lungs, answer very nearly for the proportion of oxygen which disappears; but, estimated by weight, the proportions are different, for the specific gravities of oxygen and carbonic acid are different, nearly as 34 to 47, the oxygen being the lighter of the two. 100 cubic inches of oxygen, in uniting with carbon, absorb about 13 grains weight of this element, and now form 100 cubic inches of carbonic acid.

in twenty years—4,800,000,000 tons, disregarding the odd numbers.

176. Such being the enormous quantities of oxygen removed from the air, and replaced by carbonic acid *by one only* of the operations which produce this effect on the air, and *one only* of the races of animals which perform this operation, it was matter of wonder with the earlier chemists what came of the carbonic acid thus produced, for they imagined that all the oxygen of the air must have very soon become converted into carbonic acid, and totally unfit for being breathed by animals; hence, they searched for some method by which the purity of the atmosphere was preserved. They inferred that there must be some cause continually in operation, changing the nature of this vitiated atmosphere, removing the carbonic acid, which, if it accumulated, would soon put an end to both animal and vegetable life, and render the face of the globe a barren waste, and replacing it with oxygen, the food of life for all animated beings.

177. When it was found that vegetables sometimes remove carbonic acid from the atmosphere, retaining the carbon and replacing the pure oxygen, this discovery was considered to remove the difficulty with regard to the preservation of the purity of the atmosphere, and its continual fitness for the support of animal life and combustion—it was imagined that, by one of those beautiful adjustments which abound in nature's works, the animal and vegetable creation are opposed to each other with respect to their effects on the atmosphere, being so formed, that, what the one rejects as noxious, proves the food of the other; that, while oxygen is the

matter required by animals, and carbon the n they reject, carbon is the matter required b vegetable creation,—and that they procure it fro carbonic acid expelled from the lungs of ani thus removing the carbonic acid, so noxious animals, and replacing the oxygen, so essent the same; the oxygen performing the double tion of removing the carbon from animals conveying it to vegetables. For a long time i the universal opinion, that animals and vege by their opposite actions on the atmosphere mutually adapt it for each other;—but later rimenters found, that this decomposition o carbonic acid in the atmosphere was not *alwa* effect produced by the respiration of vegetables they sometimes produced the same effect as ani namely, retaining a portion of the oxygen, an placing it more or less with carbonic acid. however, although several experiments which been performed on this subject, particularly th Mr Ellis, tend to confirm the opinion that plan not, on the whole, purify the atmosphere, later experiments, by Sir Humphry Davy others, have disposed the physiologists of the pi day to incline to the opinion, that in the cours day plants give out to the air more oxygen than take from it, and therefore that there does exi tween the two great divisions of animated nat animals and vegetables—that reciprocal depen and adjustment of each to the wants of the otl

178. But, although there were *no* processes on which decompose the carbonic acid, and r free oxygen to the atmosphere; supposing the atmosphere *does* become permanently altered i

proportion of its constituent parts ;—we would still find, that chemical examination would not exhibit to us this progressive increase in the quantity of the carbonic acid, and diminution of the oxygen. *It has been calculated, that the quantity of the atmosphere is so great, that the difference in chemical composition occasioned by all the various processes which tend to vitiate it would be so trifling, even in the long period of a hundred years, that it could not be detected by chemical analysis, and could not make any difference with respect to its fitness for the respiration of animals, so that, in fact, for a very long period indeed, there would not be occasion for any compensating process to remove the carbonic acid, and renew the oxygen.* Did the air, when altered by any chemical action, continually remain near the spot where the change took place, we would soon perceive a very marked difference in its chemical composition ; but the agitation to which it is subjected by the winds, and several other causes, produce a thorough intermixture of all its different parts, so that the loss of oxygen, and the addition of carbonic acid occasioned at any place, being soon equally diffused over the whole mass, the effect is very trifling indeed. If we compare with the total quantity of air the quantity of carbonic acid formed by man in twenty or a hundred years ; great as that may appear, it will be seen to sink into insignificance when contrasted with the prodigious quantity of the air, more than forty-five miles in height, and encompassing a sphere, of which the diameter is nearly eight thousand miles.

179. We have seen (76) that the whole weight of the atmosphere is about 53,672,142 hundred

millions of tons, and a little more; and of this, 1.5th, more than *ten million times* a hundred millions of tons, is oxygen. Also (175), we have seen that the respiration of man adds to the air in twenty years about *forty-eight* hundred millions of tons of carbonic acid gas: of this about 34 hundred millions are oxygen, (the rest being carbon—see note, page 122), which was in the atmosphere before; hence the weight of the atmosphere is *increased* only by about 15 hundred millions of tons, so trifling a quantity in proportion to the whole mass, (53,672,142 hundred millions of tons), that the increase in weight may be entirely disregarded. Thus, at the end of twenty years, by the respiration of the whole human race, as 48 is contained about a million of times in fifty-three millions, *only one millionth part of the air would have become carbonic acid*, and as 48 is contained about two hundred thousand times in ten millions (a fifth, to take a round number, of fifty-three millions), the *quantity of this gas (the carbonic acid) would bear to the quantity of oxygen the very small proportion of ONE TO TWO HUNDRED THOUSAND*. The following tabular view will convey a clearer idea of these proportions:—

	Hundred Millions of Tons.
Weight of the whole air,.....	53,672,142
Weight of oxygen alone,.....	10,000,000
Weight of carbonic acid at present in the air,.....	53,672
Weight of carbonic acid added by the } human race in twenty years, }	48
Ditto in a hundred years,.....	240

Or, to state it in another way, supposing the total weight of the air at present to be represented by the number 1,000,000 (one million), and also by 1, to show the proportions in fractions.

	Hundred Millions of Tons.
Total weight of atmosphere	1,000,000.....or...1
oxygen,.....	200,000.....or... $\frac{1}{5}$
carbonic acid at present in air.....	} ... 1,000.....or $\frac{1}{1000}$
carb. acid add- ed in 20 years by the human race.....	
Ditto in 100 years,.....	5.....or $\frac{1}{200000}$
Ditto in 20,000 years,.....	1,000.....or $\frac{1}{1000}$
Quantity of oxygen remov- ed in 100 years.....	}3.33 or $\frac{1}{300000}$

The above fractions are in relation to the *whole of the air*; in relation to the *whole of the oxygen*, the quantity of oxygen consumed in 100 years, would be as 3.333 to 200,000, or, as $\frac{1}{60000}$ to 1.*

180. Thus, twenty thousand years would elapse before the human race, at their present rate, would add to the air as much carbonic acid as there is at present, namely 1-1000th, and in a hundred years they remove only about 1-60000th of the oxygen, or 1-300th in twenty thousand years.—And, computing that all the other animals which add carbonic acid to the air, and remove the oxygen, and all the other processes which act in the same way with the air, produce in the aggregate an effect twenty or

* Supposing the oxygen removed to be equal in bulk to the carbonic added, a quantity of oxygen being about 2.3ds of the weight of the same bulk of carbonic acid.

thirty times that of the human race, it would be hundreds of years before a change would be produced, appreciable by chemical analysis, and even thousands before the atmosphere would be rendered unfit for the support of animal life. On this supposition, the amount of carbonic acid added in a hundred years would be only $\frac{1}{8000}$ ($\frac{1}{200000} \times 80$); in a thousand years $\frac{1}{800}$; the quantity of oxygen removed in a hundred years would be only $\frac{1}{8000}$ the whole oxygen, in a thousand years, $\frac{1}{800}$.

X. ARE THE CONSTITUENT PARTS OF THE AIR CHEMICALLY COMBINED, OR MERELY MIXED WITH EACH OTHER?

181. Strange as it may appear, it is now a general opinion among chemists, that *the oxygen and nitrogen of the air are not in chemical union with each other, but that they are merely in a state of mechanical mixture.*—And it is also considered that the watery vapour in the air is not *water dissolved* by air (as frequently said), but that it is there as an independent vapour, and that it would be there although the oxygen, nitrogen, and carbonic acid were entirely absent. It was formerly supposed, that the presence of the watery vapour in the air was owing to a chemical attraction subsisting between water and the air, by means of which the air lifted up water from the various bodies of water on the globe, and dissolved it, in the same way water dissolves a solid body, such as salt or sugar. But this is not the case; the watery vapour is in the air solely from the influence of heat (128).

182. There are some reasons which might

us to regard the oxygen and nitrogen of the air as existing in chemical union with each other. Oxygen and nitrogen, it is known, have a strong chemical attraction for each other, and are disposed to combine; the oxygen is heavier than the nitrogen, and if they are not in chemical union together, we should suppose that the oxygen would sink to the ground by itself, and the nitrogen float above it, like oil upon water; but this is not the case, for they are mixed in the same proportions at whatever distance from the ground, as Gay Lussac found in air which he collected at an elevation of nearly 22,000 feet, having ascended to that height in a balloon; also, oxygen and nitrogen are present in the atmosphere exactly in those proportions, estimated both by weight and by measure, in which (from the laws of chemical combination) it is known they would be united, if it were a chemical union. But, nevertheless, they are regarded as being merely mechanically mixed, not chemically combined:—for, there is no change of form (to the solid or liquid state), as happens frequently when gases combine chemically; there is no diminution in bulk, another frequent effect of chemical union, the two gases occupying separately the same bulk as they do when forming air; generally, in effecting chemical combinations, something more is required than merely bringing the materials in contact with each other, as light, heat, and gases do not combine readily on being merely mixed, but the proper proportions of oxygen and nitrogen, if merely mixed well with each other, form a gas having all the properties of air; the refractive power of the air (its power of turning the rays of light out of their direct course),

is exactly what would be expected in a *mixture* of oxygen and hydrogen ; there is no *alteration* of properties, merely a *weakening*, for the oxygen presents the same properties as in the uncombined state, only diminished in energy from the large quantity of nitrogen present ; and, lastly, there seems to be no affinity (at least a very weak one) binding the oxygen and nitrogen to each other, for the oxygen is abstracted with great ease by any substance which has an attraction for it (as has been shown in paragraphs 111-117), the nitrogen appearing to exert little or no force in retaining it. Water has the power of absorbing oxygen, though the attraction is not very great between them ; yet, even this weak affinity separates the oxygen from the nitrogen, for rain-water contains oxygen in greater proportion to the nitrogen than in atmospheric air.—Such are the leading arguments which may be adduced to show that the oxygen and nitrogen of the air are in a state of mechanical mixture, not chemically united.

183. It was supposed by some chemists (Berthollet and the late Dr Murray), that although the affinity between the oxygen and the nitrogen as they exist in the air, is not sufficient to bring them into close chemical union with each other, *it still acts and produces the effect of preserving their particles near each other, and thus counteracts the effect of the attraction of gravitation, which would tend to draw all the oxygen to the ground.* This explanation, it will be observed, has been given with the view of removing the difficulty—how the oxygen and nitrogen do not separate (the oxygen remaining undermost), if they are not chemically united. Some interesting experiments, however, by Dr Dalton of

Manchester, showed that, besides chemical attraction, there is another power in existence which would cause the two gases to remain mixed with each other, overcoming the gravitation of the heavier, which would tend to separate them.

184. Dr Dalton found, that two gases, however different in their specific gravities, and though they may have no chemical attraction for each other, mixed in whatever proportions in a close bottle, soon become equally diffused through one another. He employed, in a striking experiment on this subject, two vessels, each closed at one end, filled one with a light gas, and the other with a heavy gas; and having fitted them to each other, with a communication between them, the vessel containing the light gas being *above* the one containing the heavy gas, he found in a few hours, that there was some of the light gas in the lower vessel, and some of the heavy gas in the upper one, having in part changed places, although there was no chemical attraction subsisting between them. The gases which he chiefly employed were hydrogen, which is about sixteen times lighter than air, and carbonic acid, which is one-half heavier than air, the hydrogen being about twenty-two times lighter than the carbonic acid; but he made the experiment also with oxygen, nitrogen, and many other gases, and uniformly found the same result; in his own words, "it appears to me as completely demonstrated as any physical principle, that whenever two or more such gases or vapours as we have been describing are put together, either into a limited or unlimited space, they will finally be arranged, each as if it occupied the whole space, and

the others were not present." Each will be diffused or spread out through the whole space.

185. This intimate intermixture of the two gases cannot be attributed to chemical attraction, for there is no chemical affinity subsisting between carbonic acid and hydrogen. It must be dependent on some other power, which, acting between carbonic acid and hydrogen, causing the heavy gas to ascend, and the light gas to descend, will produce similar effects with the oxygen and nitrogen in the air; and it is now generally considered, that it is in obedience to this law, that the oxygen and nitrogen are mixed in air in the same proportion every where. Dr Dalton supposes, that though the repulsive principle acts powerfully in repelling from each other the particles of the same gas, it does not act between those of different gases; that therefore a gas, by the elasticity of its particles (82), expands into any space to which it may have access, completely disregarding any other gas which may be in that space, while the gas previously there acts in the same way, and they thus become mutually diffused through each other.

186. The principle founded on these experiments by Dr Dalton, that there is some power in operation which causes two gases in contact to diffuse themselves through each other, has received confirmation from the experiments of Mr Graham of Glasgow on this curious tendency of the gases to enter into every space to which they may have access, even though that space be already occupied by another gas. He found that this expansive tendency in each gas is so great, that the intermixture takes place even when the two gases are separated by some

substance of a porous nature, as plaster of Paris, bladder, cork, or stoneware. This property of gaseous bodies has been named, "The Diffusion of Gases;" and as it is an extremely curious and interesting subject, throwing light on many natural phenomena, we shall make a few extracts from Mr Graham's paper, which will convey some idea of this new mine which has lately been opened up in chemical philosophy.

187. "There is a singular observation of Doeberiner, which chemists seem to have neglected as wholly inexplicable, on the escape of hydrogen gas by a fissure or crack in glass-receivers, which belongs to this subject, and from which I set out in the inquiry. Having occasion, while engaged in his researches on spongy platinum, to collect large quantities of hydrogen gas, he accidentally made use of a jar which had a slight crack or fissure in it. He was surprised to find that the water of the pneumatic trough rose into this jar one and a half inches in twelve hours, and that after twenty-four hours, the height of the water was two inches two-thirds above the level of the water-trough. During the experiment neither the height of the barometer nor the temperature of the place had sensibly altered. In other experiments, he substituted glass vessels of very different forms, tubes, bell-jars, flasks, all of which had fissures. In every one of these vessels, filled with hydrogen, the water rose, after some hours, to a certain height."—We would have expected that, the atmospheric pressure acting on the liquid in the interior of the jar through the fissure by which the gas escaped, the liquid would have been at the same level exteriorly and interiorly.

"On covering one of these vessels, containing hydrogen, by a receiver—or on filling the vessel with atmospheric air, oxygen or azote, instead of hydrogen—he never observed a change in the original volume of the gas."

188. "On repeating Doebereiner's experiment, and varying the circumstances, it appeared that hydrogen never escapes outwards by the fissure without a certain proportion of air returning inwards."—This is the peculiar phenomenon pointed out by Mr Graham: *An interchange of the two gases (the hydrogen within the jar, and the air without) takes place through the fissure.* If, instead of a jar with a crack in it, the two gases be separated by some substance of a porous nature, having apertures of insensible magnitude, the interchange of the gases then actually takes place through these apertures, "being effected by a force of the highest intensity, and *if the gases are of unequal density, there is a consequent accumulation on the side of the heavy gas, and loss on the side of the light gas.* In the case of air, for instance, on the one side of the screen," the porous substance, "and hydrogen gas on the other, a process of exchanging one measure of air for 3·7947 measures of hydrogen, through the apertures, is commenced, and continues till the gases on both sides of the screen are in a state of uniform mixture."

189. Hence the reason why the water rose in the jar above the level of that in the trough; the quantity of hydrogen which passed out was greater than that of the air which passed in; and, there being less gas in the interior resisting the atmospheric pressure tending to raise the water in the jar, the

liquid was pushed up in proportion to the diminution in the quantity of the gas ; and hence also the reason why there was no change of bulk when the jar contained oxygen or nitrogen ; the densities of these are nearly the same as that of air, and the interchange (which went on in these cases also) is nearly equal. When a gas heavier than air (carbonic acid) was in the jar, an excess of air *passed in*, in conformity with the law developed by Mr Graham, and marked in italics above. In one experiment, a bulk of carbonic acid gas equal to 176·6 passed out of a vessel, and was replaced by 217·6 of air, the jar then containing 41 parts more gas than before.

190. The quantities by measure (or volumes) of two gases which are thus interchanged are, “in the case of each gas, inversely proportional to the square root of that gas.”

191. “A simple instrument, which I shall call a diffusion-tube, was constructed as follows : A glass tube open at both ends was selected, half an inch in diameter, and from six to fourteen inches in length. A cylinder of wood, somewhat less in diameter, was introduced into the tube, so as to occupy the whole of it, with the exception of about one-fifth of an inch at one extremity, which space was filled with a paste of Paris plaster of the usual consistence for castes. In the course of a few minutes the plaster set, and, withdrawing the wooden cylinder, the tube formed a receiver closed with an immovable plug of stucco. The less water employed in slaking the Paris plaster, the more dense is the plug, and the more suitable for the purpose. In the wet state the plug is air-tight ; it was therefore dried, either by

exposure to the air for a day, or by placing the instrument in a temperature of 200° Fah. for a few hours; and thereafter was permeable by gases, even in the most humid atmosphere, if not positively wetted. The tube was finally graduated by means of mercury into hundredths of a cubic inch, and the notation, as is usual with gas-receivers, counted from the top. When such a diffusion-tube, six inches in length, was filled with hydrogen over mercury, the diffusion, or exchange of air for hydrogen, instantly commenced, through the minute pores of the stucco, and proceeded with so much force and rapidity, that within three minutes the mercury attained a height in the receiver of upwards of two inches above its level in the trough. Within twenty minutes the whole of the hydrogen had escaped."

192. The quantity of gas that escapes from the interior must be in proportion to the quantity of gas exteriorly: if the jar be covered with a receiver, so that there is a very small quantity of air between the jar and receiver, little or no gas will escape from the inner jar, as in Doebereiner's experiment (187). If the jar be exposed to the air, as the gas interiorly is as nothing compared with the whole mass of air, the diffusion must go on till the whole of the gas has escaped.

193. "The ascent of the water in the tube, when hydrogen is diffused, forms a striking experiment. In a diffusion-tube fourteen inches long, the water rises six or eight inches in as many minutes. The column of water attains in a short time its maximum height, at which, however, it is never long sustained; for, as in Doebereiner's experiment, air is all along entering mechanically through the porous plug

in such circumstances, from the pressure of the atmosphere; and after the diffusion is over, the water subsides in the course of several hours to the general level."

194. "I may be allowed to mention an application of the law of diffusion, in explanation of the mechanism of respiration. The cavity into which air enters during respiration, consists, first, of a large tube, the windpipe; secondly, of smaller tubes, into which the windpipe diverges; and, thirdly, of a series of still smaller tubes, diverging from the last, themselves ramifying to an indeterminate extent, till at last the tubes cease to be of sensible magnitude, but are believed to terminate in shut sacs. The capacity of the whole cavity cannot easily be determined, but we may estimate it at 300 cubic inches. In a natural expiration, about 20 cubic inches, or 1-15th of the contents, are thrown out, from the application of a general pressure to the whole. But it is evident, that these twenty cubic inches will be the twenty cubic inches nearest the outlet, or the contents of the larger tubes. The contents of the second-sized tubes will advance at the same time into the largest tubes, but no further, and will recede again into their original depositories on the next inspiration, which will fill the larger tubes with fresh air; which identical quantity will again be expelled in the next expiration. This illustration is perhaps too strongly stated; but it is evident that, in ordinary respiration, the slight mechanical compression will have little or no effect in emptying the most distant tubes, or the ultimate air-cells, of their contents. The bulk of the air, also, is not altered during respiration, although, for a quantity of

oxygen, carbonic acid gas is substituted. This substitution, which is the great end of respiration, undoubtedly takes place most abundantly in the minute and distant air-cells, which present the largest surface to the blood ; and the carbonic acid there produced must be moved along the smaller tubes by the diffusion-process (which we know to be extremely energetic, and also inevitable), till it is thrown into the larger tubes, from which it can be expelled by the ordinary action of respiration. But the action of diffusion is always twofold : at the same time that carbonic acid is being carried outward from the air-cells, oxygen is carried inward in exchange, and thus the necessary circulation kept up throughout the whole lungs."

RECAPITULATION.

195. Having now brought to a conclusion our account of the atmosphere, it may be well briefly to recapitulate the leading circumstances in its history, which are worthy of attention.

196. I. The air is a substance or body, capable of being felt, and giving resistance to other bodies in motion, of exerting force itself when in motion, as seen in the windmill, or in the sailing of vessels, and giving support to light bodies, as birds, clouds, a balloon, &c. II. The air has weight, like other bodies, a hundred cubic inches weighing 31·0117 grains ; and in consequence exerts a certain downwards force or pressure on every body beneath it, amounting to a weight of 14·7 pounds on every square inch, and being able to support a column of water to the height of 33·87 feet, or of mercury to the height of 30 inches :—hence the pneumatic trough and the

barometer. III. The air is elastic;—it is reduced to a smaller bulk when exposed to a greater pressure, its particles being made to approximate; and when the pressure is removed, its particles recede, and it assumes its former size. Hence the increasing rarity or thinness of the atmosphere in the upper regions, where the pressure is continually decreasing. IV. The air is supposed to extend to a height of about forty-five or fifty miles above the surface of the earth. V. The air is of a blue colour, but very faint, so that the colour is perceptible only when a very large body of air is presented to the eye. VI. The air is a compound body, consisting in 1000 parts by weight, of 756 parts of nitrogen, a gas which cannot support combustion or respiration, 233 parts of oxygen, a gas which causes these processes to go on with too great activity, 10 parts of watery vapour, 1 part of carbonic acid gas. VII. The air is continually undergoing various changes, which more or less alter its chemical composition.—By the breathing of animals, carbonic acid gas and watery vapour are added to the atmosphere, and oxygen removed. Plants, during germination, remove oxygen and replace it with carbonic acid; at times they produce the same effect by their leaves, while these same organs at other times remove carbonic acid from the air, and replace it with oxygen; they also add watery vapour to the atmosphere. Fermentation adds carbonic acid and watery vapour to the air, frequently diminishing the proportion of oxygen. Combustion or burning, in general, converts the oxygen into carbonic acid and watery vapour. VIII. The air is essential to the existence of the animal and vegetable creation in a great number of

ways. The oxygen serves to remove carbon from the body, by converting it into carbonic acid gas in the lungs, combines with combustible bodies, thus producing heat and light, and plays an important part in many other operations, as fermentation, germination, &c. The nitrogen dilutes and weakens the action of the oxygen. The carbonic acid and watery vapour, though not so directly essential to animal life as the oxygen and nitrogen, the removal of either of which for a very short time would be attended with fatal consequences, have still important offices allotted to them in the general economy of nature. IX. The total mass of air being so immense, and all its different parts being so thoroughly mixed by the winds as well as by the diffusion-process, the changes effected on the air by the various processes just mentioned would not make a *perceptible* difference in many hundred years, and it would even be thousands of years before the air would be at all unfitted for any of the purposes for which it has been formed, this being still further (if not altogether) retarded by the action of vegetables, which seem to counteract the effects of the various processes which would unfit it for the support of combustion, respiration, &c. X. The various ingredients of the air, being each required for so many different operations in which the others are not concerned, are not bound to each other by chemical attraction, which would prevent each being readily supplied separately to that body which requires it—they are in a state of mere mechanical mixture, so that they are easily separated from each other by substances which have any attraction for them, being nevertheless diffused through each other

in the same proportions every where, according to the law pointed out by Dr Dalton.

197. Here, then, we conclude our account of the atmosphere, certainly the most extraordinary substance with which we are at present acquainted ;—generally deemed invisible, it yet forms the most beautiful and magnificent coloured object we see—the blue sky ; so thin and attenuated as to give rise to the proverb, “ light as air,” it yet exerts an enormous pressure on the various bodies on the surface of the earth, being, in its entire mass, as heavy as a globe of lead sixty miles in diameter, and, when in motion, possessing a power or force which nothing can resist. Although we see *nothing* around us, yet the air is every where present, and is the most universally diffused substance in nature. It is elevated many miles above our heads, and descends into the deepest cavities in the earth. It penetrates into every recess, however narrow the entry, occupies every space in or about the earth that is not occupied by something else ; insinuates itself into and fills up the cavities which exist more or less in all solid bodies, animate or inanimate ; and whenever any substance is removed, rushes in on all sides and occupies the space thus left vacant. This apparent *nothing* is the medium of heat, light, and sound ; contains a great variety of substances, all constantly and actively engaged in important operations at the surface of the earth, adapting it for the abode of living beings ; and to many of these living beings is so necessary that they cannot live even a few moments without it. It is altogether one of the most wonderful of nature’s works, and there are no subjects of contemplation more interesting than the

nature of this powerful agent, and the innumerable purposes to which it is applied in supporting the existence and contributing to the welfare of animated beings.

CHAPTER IV.

WATER.

198. We shall now proceed to investigate the nature and properties of water, the compound which, next to air, has the greatest claims on our attention : next to air, it is perhaps the most universally diffused, and the most useful and important of all the bodies on the surface of our globe.

199. Water is a substance with which we are all familiar ; it is not necessary, as in the case of air, to demonstrate that there is such a body, or that it has weight and all the usual properties of matter. Its existence is obvious to many of our senses, and its weight or gravitating power is known to every one. Water exists almost every where. It forms the mass of the ocean, and of all rivers, lakes, pools, and springs. It exists abundantly in the atmosphere in the form of a colourless vapour ;—this transparent vapour, becoming condensed, gives rise to the varied phenomena of clouds, fogs, rain, dew, hail, hoarfrost, and snow. At the poles it becomes solid, and forms immense fields and even mountains of ice. At great elevations, as on the summits of high mountains, it exists in the state of beautiful feathery crystals, called snow ; and at particular seasons, it assumes these forms near the surface of the earth,

and descends to the ground, in our own climate. It combines chemically with other bodies, and sometimes in this way also assumes the solid form, as in slaked lime or stucco. Perhaps there is not another substance in nature which can assume such a variety of forms, or undergo so many changes, being quite a Proteus in this respect. What contrast can be more striking than between the light and transparent vapour in the air on a clear day, which eludes both sight and touch, and an opaque, hard, compact snow-ball, which most persons have both seen and felt? In one or other of these forms, water is present almost every where, contributing, in no small degree, by its various actions, both chemical and mechanical, in sustaining the life and order of the world around us, and giving to external nature her beauty, freshness, and perpetual variety.

200. Water was one of the *elements* of the ancients. This might be expected, for, excepting air, there is perhaps no substance which has so much the appearance of an elementary form of matter. But the progress of modern chemistry has done with water as with air—shown that it is a compound.

201. Water, as we find it in the ocean, or in rivers, lakes, springs, &c., is a very compound substance, containing many different ingredients; but, like the air, it consists chiefly of *two* substances, the others existing in it in a comparatively small proportion, although these sometimes have a considerable effect upon its properties. The chemical composition of water was discovered by the celebrated Cavendish, about the year 1781, when the experiments which led to the discovery were performed. It is proper to mention, however, that the late illustrious

James Watt, independently of Cavendish, had at the same time formed a very correct notion of composition of water, which he communicated in a letter to Dr Priestley.

I. DECOMPOSITION AND FORMATION OF WATER, WHICH IS SHOWN TO BE COMPOSED OF TWO SUBSTANCES WHICH ASSUME THE GASEOUS FORM WHEN SEPARATED FROM EACH OTHER, HYDROGEN, AN INFLAMMABLE BODY, BUT WHICH CAN SUPPORT THE COMBUSTION OF OTHER BODIES, AND OXYGEN, WHICH HAS THE LATTER PROPERTY BUT CANNOT ITSELF BE MADE TO BURN.

1. *Analysis of Water (separation of its constituent parts from each other).*

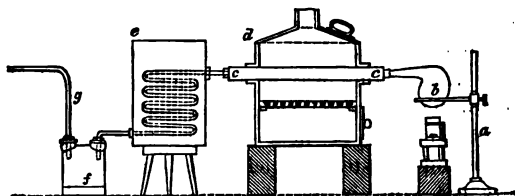
202. One of the constituents of water may be procured from it in the following manner: A few iron turnings, or a coil of iron wire, be put in an iron tube which is made to pass through a furnace, so that the tube can easily be rendered hot. The tube is open at both ends, each of which must be without the furnace. Fit the beak of a retort containing some water into one of the ends, and into the other adapt a tube, the extremity of which is made to dip under the water in a pneumatic trough in the same way as the retort in figure in page 70, similar preparations being made for collecting any gas that may be disengaged. A bladder quite flaccid, being carefully pressed to expel all the air, may be tied by the neck to the end of the tube, instead of making it dip into water in the pneumatic trough: any gas which comes from the iron tube will pass into the bladder, w

it will occupy and distend. Let a fire be kindled in the furnace, the tube within it be brought to a red heat, and apply heat to the bottom of the retort. The water in the retort will be converted into steam, which will pass into the tube, and there come into contact with the iron turnings or iron wire. Almost immediately after the steam has reached the heated part of the tube, a quantity of gas will be disengaged from the extremity dipping into the pneumatic trough, or having the bladder attached, which may be collected in the manner already described.

203. It will be found that a considerable change has been effected. The gas which is collected at the trough cannot be the steam which arose from the boiling water in the retort, for steam whenever it comes into contact with cold water is condensed, and again assumes the liquid form; the gas which is procured, however, passes through the water in the trough without losing its gaseous form, from which circumstance alone, we may infer that it is very different from the steam which passed from the retort.

204. The following figure (7) will illustrate an apparatus for performing this experiment in such a way that the quantities of the various products may be estimated. A known quantity of pure water is placed in the retort (*b*), and made to boil. The extremity of the retort fits into a porcelain tube (*cc*), which passes through the furnace (*d*). From the other end of the porcelain tube in the furnace, a tube passes in a spiral form through the condenser (*e*), which contains cold water. It then proceeds from the lower part of the condenser to the bottle

Fig. 7.—*Apparatus for the Decomposition of Water by Iron, at a high Temperature.*



(*f*), and from this bottle also proceeds another tube (*g*), conveying any gas formed to the pneumatic trough. By means of the condenser, any steam which may pass unchanged over the coil of iron wire, is condensed into water, and flows into the bottle, so that its quantity may be exactly known. By these means none of the products are allowed to escape.

205. If the iron wire or turnings be weighed before and after the experiment, the iron will be found to have increased much in weight. The water in the retort must have diminished in weight, so much of it having passed into the tube in the form of steam. Any steam which escapes from the tube in the state of steam, is condensed and collected in the form of water. By comparing the weight of this with the weight which the water in the retort has lost, it will be found, that a considerable part of the steam which arose from the liquid has entirely disappeared (that is, is no longer to be found in the state of steam or water), for the weight of the quantity thus collected will be much less than the weight

of that which has passed out of the retort ; thus we shall be enabled to know exactly *how much of the steam has been altered by passing through the tube.* The estimate of the changes effected by the action could not be so well or so easily effected if an iron tube had been used, as this itself would be acted upon in the same way as the iron. By using the earthenware tube, however, this is avoided.

206. It may be necessary to observe that the water and the steam which arise from it are identically the same in chemical composition, the only change effected on the water by the heat being the increase between the distance of its particles, so that it occupies a much larger space than before. The relations of the *constituent particles* (61) of the water remain unchanged ; but the *integrant particles* (61) are repelled from each other. When steam strikes upon any cold substance which withdraws the heat, it returns to the state of water. Chemically speaking, water and steam may be regarded as one and the same substance.

207. A certain quantity of the steam, then, has undergone a chemical alteration from passing over the iron. Now, it will be found on weighing them, that the gas collected in the pneumatic jar is much lighter than the steam which has disappeared ; hence, some of the matter of the steam is wanting ; but the iron has increased in weight, and therefore we may presume that the matter which it has acquired is that which the steam has lost. This view is confirmed by the experiment of weighing all the materials, for it will then be found that *the additional weight which the iron has acquired, added to the weight of the gas which has been procured, exactly*

corresponds to the quantity of steam which has disappeared.

208. In the experiment just described, the materials used were iron and water; iron is a simple substance, and as the iron used has increased in weight from the steam passing over it, having thus taken something from the steam, it must be next endeavoured to ascertain the nature of this matter which has been abstracted from the water.—We have seen, when considering the nature of air, that the oxygen which it contains possesses in a high degree the power of supporting combustion or burning, and that this arises from the chemical attraction between oxygen and the burning body. Now, iron is a combustible body, but it can hardly be made to burn in air owing to the oxygen being weakened by the presence of such a great quantity of nitrogen; if it be set fire to, however, in oxygen gas, the oxygen will disappear, the iron will rapidly unite with it, undergoing combustion, being melted, and converted into a black brittle substance, which, from consisting of iron and oxygen, is called an *oxide of iron*. It has been found, that the matter into which the iron wire or iron turnings in the tube is converted is of the same nature as this oxide of iron formed by burning iron in oxygen. The iron has therefore acquired oxygen, and as there was no source except the steam from which the oxygen could be procured, water must contain oxygen. We have already become acquainted with the characters of this important element, as entering into the composition of air.

209. If the gas collected at the trough be examined, it will be found to have properties very

different from those of oxygen, nitrogen, or carbonic acid, the only gases which we have as yet examined. Like the latter of these gases, it cannot support either combustion or respiration, a light being extinguished and an animal suffocated if they be immersed in it; but whenever a light, as the flame of a candle, is brought into contact with it, the gas itself takes fire, and burns with a reddish flame which gives little light, but produces a great quantity of heat. It will also be found, that this gas is remarkably light, nearly sixteen times lighter than atmospheric air, its specific gravity being 0.0694, and 100 cubic inches weighing only 2.153 grains. It is called HYDROGEN, a name which indicates that it enters into the composition of water, being derived from two Greek words, *ὕδωρ* (*hudor*), "water," and *γενναω* (*gennao*) "to form or produce." It was at first known by the name of "inflammable air," from the readiness with which it takes fire, and "phlogiston," from the idea which prevailed at one time, that it is the matter which gives rise to heat; this word being derived from the Greek word *φλογίζω* (*phlogidzo*), "to inflame" or "to catch fire;" but it is now always termed "hydrogen."

210. Here, then, we have seen, that water can be made to give out an inflammable gas, and that what remains after this gas has been separated from it is oxygen (in this case united with iron immediately on separating from the hydrogen). Hence water contains these two substances; and, as by operating cautiously the whole of a given quantity of water might be converted in this way into these two substances (the gas which collects in the trough and the oxygen which unites with the iron), it is clear that

water must be entirely composed of these two bodies. It has also been found, that these two bodies are simple in their nature ; whatever experiments may be performed with them, they cannot be resolved into any other kinds of matter ; therefore, in these, we have what, in the present state of our knowledge, we must consider as the *elements of water*.

211. Something similar to what has been described as taking place in the experiment with the iron tube traversing the furnace occurs when a little water is thrown on burning coals. There is often an unpleasant odour produced which cannot arise from the vapour of the water produced by the heat, for steam has not any unpleasant smell. But the water is decomposed ; the charcoal of the coal, like iron, has a very great attraction for oxygen, and abstracts it from the water, while the hydrogen, which is thus set at liberty, unites in part with some matters in the coal, and forms various compounds, thus giving rise to the disagreeable smell. This would be found to take place, however pure or clean the water might be. It is not the hydrogen alone which causes the offensive odour, for pure hydrogen has no smell—it is the compounds of hydrogen with the charcoal and sulphur of the coal. Sometimes also, sprinkling water on a fire causes a blaze or flame like that of spirits burning ; this arises from the decomposition of the water, and the hydrogen being set fire to at the same time. The same will be observed, if, instead of coals, which furnish charcoal to unite with the oxygen of the water, iron be used. If a piece of iron, at a white heat, be plunged in water, the iron will attract oxygen from the water, by which the hydrogen will be

set at liberty, and will rise to the surface in the gaseous form. If a jar full of water be placed over the point at which the gas emerges from the liquid, a little hydrogen gas may actually be collected in this simple way.

212. When the iron is removed from the water, it is found to be somewhat altered: there is a thin film of a black brittle matter covering it, which can be easily broken off, and is found to be very different from the tough iron below. This is the compound formed by the union of the iron with the oxygen of the water. It is found to be similar in composition to the matter into which the iron was converted (208), similar to the matter which is formed when iron is made to burn in oxygen gas—and similar to the black earthy scales that fall from a piece of red-hot iron when hammered on the anvil, known in Scotland by the name of *smiddy dust*. They are all *oxides of iron*, the same chemical action having taken place in all these different cases—the union of iron and oxygen.

213. It will be seen, that the manner in which we procure hydrogen from water is exactly similar to that in which we obtain nitrogen from air, namely, employing some substance which has an affinity for the oxygen, with which each of these matters is associated. In the case of water, a metal is the substance best adapted for this purpose; and by its affinity for the oxygen, assisted by the heat, it is enabled to abstract the oxygen, while the hydrogen, being loosened from its chemical attraction with the oxygen, assumes that form which is natural to it in the uncombined state, comes away to find room for

itself in its expanded condition, and leaves the oxygen in the solid state in union with the iron.

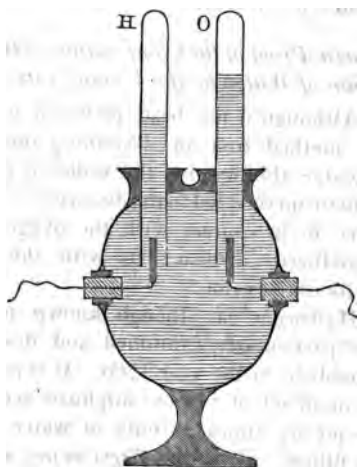
214. There is another method of proving the composition of water by analysis, and one more satisfactory still, for we obtain directly both the elements of water in the uncombined condition, and can easily resolve the whole of a quantity of water into the oxygen and hydrogen of which it is composed. Here, however, we have to call in the aid of a new power, one to which we have not hitherto alluded, namely the **ELECTRIC INFLUENCE**.

215. Every one has heard of the electrical machine, and the galvanic battery, by which so many curious phenomena are produced. The electric machine consists chiefly of a glass cylinder or glass plate, which is made to revolve rapidly, and while revolving to undergo friction from being pressed against a silk cushion attached to the machine. The galvanic battery consists of a number of rows of plates of zinc and copper, with intervals between each pair of plates, set in a box, which is then filled up with some acid fluid, as diluted nitric and sulphuric acids. A chemical action goes on between the liquid and the metallic plates. In both of these cases a particular power or influence is excited, called in the first case electricity, in the latter, galvanism; but they are believed to be modifications of the same general agent. It is not well known what this influence is, but it lies under our control to a certain extent, and, by particular means, can be collected and conducted from one body to another, or transmitted through bodies. Among the many remarkable effects which this subtile

agent can produce, perhaps the most curious is its power of decomposition, that is, of separating substances which are chemically united.

216. When it is desired to examine a liquid by means of the galvanic energy, this influence is transmitted from the battery by means of wires attached to each end of it, and which are introduced into the liquid to be decomposed, so as to be at a short distance from each other. If the liquid be acted upon, one of its elements will appear at one wire, and the other at the other wire, and they will assume that form which is natural to them when separated from each other. If a quantity of water be in this manner subjected to the galvanic influence, at the moment in which the wires are placed in the liquid, each will be surrounded with a crowd of globules of gaseous matter, and if there be provided, above the extremities of the wires, small tubes filled with water, and so placed as to collect any gas that may be disengaged at the wires, each gas will ascend and occupy the tube which is placed above it, in the same way in which gas issuing from the beak of a retort ascends to the summit of a pneumatic jar. After the decomposition of the water has gone on for some time, and a considerable quantity of gas has been collected, it will be found that the gases evolved from each wire are different from each other, that the quantity of one is exactly double that of the other, and that the one in largest quantity has all the properties which characterize hydrogen (209), while the other manifests the characters which distinguish oxygen (102).

217. The following figure (8) will illustrate this experiment.

Fig. 8.—*Decomposition of Water by Galvanism.*

The water is contained in a globular vessel with two openings at the upper part, into which are inserted two tubes open at the lower extremity, and an opening at each side through each of which passes a gold or platinum wire bending upwards into one of the tubes, flattened out at the extremities, or with a slip of foil of the same metal attached. The simple wire will answer very well. The platinum wires are connected to the battery by copper wires. The water displaced by the gases evolved drops out at the holes where the wires enter.

218. As water, then, is resolved into oxygen and hydrogen gases by means of the galvanic influence, and as these gases, as far as we know at present, are

simple bodies, from this experiment also we infer that these are the two substances which compose this liquid—its elements.

2. Synthetic Proof of the Composition of Water, i. e. Formation of Water by the Union of its Elements.

219. Although it has been preferred to take the analytic method first in describing the composition of water, this was not the order of discovery; the synthetic method led to the discovery. Hydrogen is set fire to in contact with the oxygen: water being produced, furnishes us with the synthetic proof of its composition.

220. Hydrogen gas, though known previously, was first particularly examined and described by Mr Cavendish, in the year 1766. It is procured by the action of oil of vitriol (sulphuric acid), mixed with about six times its bulk of water, and zinc or iron filings. A brisk effervescence soon commences, and this gas is disengaged from the liquid. Several years after the discovery of the gas, Macquer, a celebrated French chemist, along with another chemist, made an experiment with the view of ascertaining if any soot is given off from the flame which is produced when hydrogen gas burns, supposing that the flame of the hydrogen might resemble the flame of a fire or candle in this respect. For this purpose, they put into a bottle, having a tube with a narrow bore fixed into the neck, the above-mentioned materials for making hydrogen; when the gas began to issue from the aperture it was set fire to, and a white china saucer was held above the flame, that any soot deposited might be distinctly

seen on the white ground.* No soot appeared—the saucer remained perfectly clean—and *was found to be moist, being covered with a quantity of very small drops of a clear limpid fluid resembling water.* But the true explanation of this result did not occur to them. Shortly afterwards, Lavoisier and another chemist tried a somewhat similar experiment, with the view of ascertaining if any carbonic acid were formed during the burning of hydrogen gas. For this purpose, they set fire to a quantity of hydrogen in a bottle, and while it was burning they poured into the bottle, making it pass through the flame and agitating it well, a quantity of lime-water; but the lime-water did not indicate the presence of any carbonic acid. Dr Priestley afterwards tried a similar experiment of burning hydrogen, and found the sides of the vessel bedewed with moisture; he supposed that the two gases, the hydrogen and the air, in consequence of the combustion, *deposited in the liquid form the watery vapour they previously contained,* not that any water was produced by the union of the two gases.

221. To Mr Henry Cavendish is due the merit of having formed a right conjecture regarding the composition of water, and of designing the most satisfactory experiments by which this is proved. Expressly with the view of discovering what comes of the gases which disappear during the burning of

* In performing this experiment, care must be taken that the bore of the tube be small, that it fit tightly into the bottle, and that the light be not applied for some little time after the gas has begun to be disengaged from the liquid. The object of these precautions is to prevent any explosion, which would take place if any air got into the bottle.

hydrogen, he burned a quantity of hydrogen gas with about two and a half times the quantity of common air, *and caused the burnt gases to pass through a perfectly dry glass tube eight feet in length, and kept cool; one hundred and thirty-five grains of water were procured, being condensed in the inside of the tube.* He also exploded in a close vessel a quantity of oxygen gas, with about twice its bulk of hydrogen, by applying a light to the mixture, and found that in this case also a quantity of water was the result of the combination. As oxygen and hydrogen disappeared in both of these experiments, while water was formed, Mr Cavendish concluded, that the oxygen and the hydrogen had combined chemically, and that the water was the produce of the combination.

222. An experiment on a very large scale, demonstrating the composition of water, was shortly after performed by three distinguished French chemists, and as it was a very remarkable experiment, if we consider the time during which it lasted, the great quantity of the materials employed, and the uncommon accuracy of the result, it may not be uninteresting to describe it briefly.

223. Fourcroy, Vauquelin, and Seguin, three eminent French chemists, who flourished about the close of the last century, commenced this experiment on Wednesday, May 13, 1790, and it was brought to a conclusion on Friday, the 22d of the same month. The hydrogen was procured by zinc, which, after being melted, was rubbed to a powder in a hot mortar while it was solidifying, and strong oil of vitriol diluted with about seven times the quantity of water. In order to render the gas as pure as

possible, to rid it from any watery vapour or other gases (such as sulphuretted hydrogen or carbonic acid gas) which might be mixed with it, it was passed through caustic potash, which retained the impurities, allowing the hydrogen to pass freely through it. The oxygen was obtained by heating the hyper-oxy muriate of potash (now called chlorate of potash), and was purified in a similar manner. The hydrogen used in the experiment occupied the bulk of 25963·568 cubic inches (upwards of twenty-five thousand cubic inches), the weight of it being 1039·358 grains. The oxygen employed was about half the bulk of the hydrogen, namely 12570·942 cubic inches, weighing 6209·869 grains. The weight of both gases was thus 7249 grains. The combustion of the hydrogen with the oxygen was continued for one hundred and eighty-five hours, with little intermission, and the apparatus was not quitted for a moment, the experimenters resting themselves in the laboratory alternately when fatigued.

224. Such was the care and accuracy with which this celebrated experiment was performed, that, of the 7249 grains weight of materials employed, only about five grains were lost. The oxygen and hydrogen were converted into water by the combustion, and of this substance, 7244 grains weight (about 15 ounces) was procured: and the water was very pure, resembling distilled water. This extraordinary experiment proved to a demonstration the composition of water, for not only was water produced by the combustion, but the weight of this was exactly the same as that of the materials used, showing *that the whole had been converted into water, that nothing else had been formed*:—the loss of five

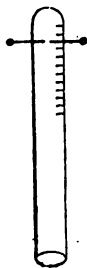
s, 1-1449th part of the whole, is too trifling to be taken into account.

5. The first product formed by the union of hydrogen and oxygen is not *water*, but *watery vapour*; this watery vapour, however, soon passes to the state of water, if the vessel in which it is placed be not at a high temperature. In the experiments we are describing, the watery vapour formed passes almost immediately to the liquid state, from being cooled by the cold bodies surrounding it.

6. Another way to cause oxygen and hydrogen to combine, is to subject them to the electric influence, for that singular power, which, we have seen, is capable of separating them when united, can also produce the opposite effect of causing them to unite when in contact in the uncombined condition. These two gases be set together in a jar in the proportions of one part by measure of oxygen to two parts of hydrogen, and an electric spark transmitted through the mixture, an explosion takes place.

Heat and light are produced, the gases combine chemically, a quantity of watery vapour is formed, and the two gases entirely disappear. The gases which are produced from water by the galvanic process (216), would, on being mixed together having an electric spark transmitted through them, combine and return to the state of water. The heat produced during the union of the two gases is very great, and has the effect of causing the compound formed to expand greatly (57), to about fifteen times the volume of the mixture at first. In consequence of this

Fig. 9.

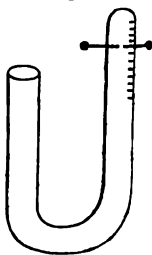


some precaution must be used to prevent the gas being forced out of the tube or jar, which is avoided by using only a very small quantity of the gases at the top of the jar, the rest being filled with water or mercury. The liquid is pushed down by the expansion of the gases, and rises again when they have cooled. If water be used, the vapour formed will be condensed, and the tube entirely filled with water. If mercury be used, the vapour will also be condensed, and will float on the surface of the mercury, which will rise almost to the top of the tube, as the quantity of liquid formed is exceedingly small. See Fig. 9, Volta's Eudiometer (134). The tube is set in a pneumatic trough.

227. Hence, hydrogen is used in the analysis of air, to ascertain the proportion of oxygen it contains. Dr Ure's Eudiometer is recommended for this purpose. Its form is shown in the adjoining figure. A glass tube closed at one

Fig. 10.

extremity, bent in the form of a syphon, and with the limbs of nearly equal length, is the instrument employed. The closed limb is graduated, and near the extremity of this leg, two platinum wires pass through the glass into the interior, at opposite sides, and nearly meeting each other. Introduce into the sealed extremity (at the pneumatic trough) three measures of the air to be examined, and two measures of hydrogen. The remainder of the tube is filled with mercury, excepting about two inches at the open end to be left with common air. The open end is then closed by the finger or thumb, and



an electric spark transmitted through the gaseous mixture. The gases will expand at first, and press upon the mercury, but this pressure will be borne by the air at the extremity of the tube closed by the finger, and when the mixture is cool, and mercury has been added till it is at a level in both limbs, it will be found that there is less gas in the closed limb, all the oxygen having united with hydrogen and formed watery vapour, now condensed, as the instrument has cooled. As one measure of oxygen unites with two of hydrogen, one-third of the diminution in the bulk of the gas indicates the proportion of free oxygen contained in the mixture.

228. The gases may also be made to act chemically together and form watery vapour, if they be exposed to a great pressure. This was done by M. Biot. He introduced a mixture of the two gases into a syringe, having a glass bottom and a piston moving air-tight up and down the syringe, which is a strong cylinder made of metal. The piston received a sudden and violent stroke, so that the mixture of the gases was much compressed. A very brilliant light was produced, accompanied with a loud report, and the gases expanded so much that the glass bottom was driven out. This is rather a dangerous experiment. It would appear from this experiment, that in the ordinary state of oxygen and hydrogen, their particles are at too great distances to affect each other chemically, for chemical attraction does not act except between bodies the particles of which are in the closest contact. By compressing the gases, however, their particles being brought so near that chemical attraction can act between them, they instantly combine.

229. Thus, there are three methods by which a mixture of oxygen and hydrogen may be made to combine and form water—by applying a light, which acts by the intense heat—by the electric energy—and by exposing the mixture to a strong pressure.

230. There are other and simpler modes of showing the production of water by the union of oxygen and hydrogen. Let a quantity of hydrogen be set fire to in a jar, the jar being filled with hydrogen on a pneumatic trough, containing water in the usual manner. When the jar has been filled with the gas, a small shallow tray or saucer, wide enough to cover the mouth of the jar, is applied close to the mouth of the jar while still under the surface of the water, and the tray being held steadily in that position, the jar is lifted out of the water without any of the gas escaping. It is then to be inverted, that is, the mouth turned upwards, and the tray is to be removed, a light being applied to the mouth of the jar at the moment in which this is done. The hydrogen will take fire and burn away in a very short time. Now, if the sides of the jar were clear and transparent before the gas was burned, as they would most likely be from the effects of the water with which it was filled before the gas passed into it,—it will be observed, that after the firing off of the gas, the sides of the jar will have lost their clearness and transparency, and will be quite opaque, assuming the same appearance which every one must have observed in a pane of glass in a window when any person breathes upon it. The cause is the same—the deposition of moisture on the glass. The combustion of the hydrogen is analogous to other common cases of combustion, namely, a union

of the burning body with oxygen; by the union of the hydrogen with the oxygen of the air watery vapour is produced, which, striking against the cold sides of the vessel, becomes condensed and gives rise to the opacity. If the finger be drawn along the glass, it will be rendered quite clear at the parts the finger has touched, the deposited moisture being rubbed off. This is perhaps the easiest way in which it can be shown that water is the product of the union of oxygen and hydrogen.

231. By operating in the manner which will be understood from the accompanying figure, the formation of water may be made still more manifest, and a quantity of it may be collected. Let a bladder having a stopcock attached to one end be filled with hydrogen. This is done by means of a jar such as that shown at B in the figure in page 54. This jar is first to be filled with hydrogen in the usual manner, and the bladder in a flaccid state (all the air being pressed out of it) is to be fixed by the stopcock to the top of the jar in such a way that on opening the two stopcocks there will be a free communication between the bladder and the jar. When the stopcocks are turned so that the communication is opened, and the jar depressed in the water, so that the level of the water interiorly is lower than that of the exterior water; as water always comes to a level, the water will be pushed up in the interior of the jar by the pressure of the exterior water, the empty bladder affording a retreat to the gas; and by continuing to depress the jar, the bladder may be quite filled with the gas. The stopcock at the mouth of the bladder is then turned so as to confine the gas in the bladder, which is then

removed from the jar. A tube terminating in a narrow aperture is then to be fitted on to the bladder; on turning the stopcock and pressing the bladder the gas will be expelled through the tube, and will take fire on a light being applied. If a cold bell jar be held over the flame (of

Fig. 11.

course at some distance), the watery vapour arising from the burning hydrogen striking against the cold glass, a considerable quantity of water will be deposited in drops on its surface. Dr Henry recommends for this purpose, instead of a jar, a large glass globe with two openings, a wide one for admitting the tube attached to the bladder, and a narrow one terminating in a tube, by which the heated air may pass out. Or, the experiment performed by Macquer, to discover if any soot be deposited from the flame of burning hydrogen (220) may be substituted. This experiment (by which a flame is produced without any visible substance giving rise to it) is known by the name of the **PHILOSOPHICAL CANDLE**.

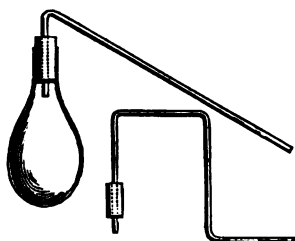


232. From all these experiments, then, it will be evident that water contains these two bodies, oxygen and hydrogen, and these only.—No chemical operations can extract any other kind of matter from it;* the whole of a quantity of water may be resolved into these two bodies; and water can be formed from these bodies alone.

* It will be understood, that here pure or distilled water is meant—that we refer to that substance which forms the main body of any common water, exclusive of the various matters which are occasionally present in small quantities.

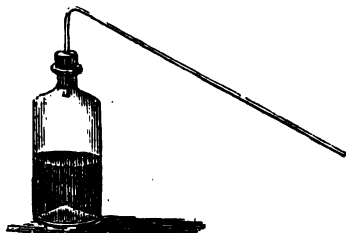
233. Hydrogen may be prepared by putting into a retort the materials mentioned in par. 220. Instead of iron filings, granulated zinc may be used. This is prepared by melting a piece of zinc, and dropping it while fluid into a vessel of cold water from a height. Instead of a retort, a flask with a cork and bent tube passing through the cork may be used, as shown in the adjoining figure. Or, a

Fig. 12.



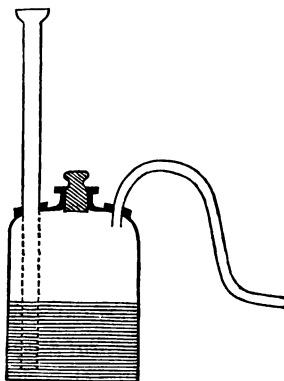
common phial with a cork and bent tube adjusted into its neck may be used. The bent tube may be of glass or block tin. See Fig. 13.

Fig. 13.



234. The best apparatus for preparing hydrogen, when a small quantity is required, is a bottle with three openings, as seen in the adjoining figure (14).

Fig. 14.

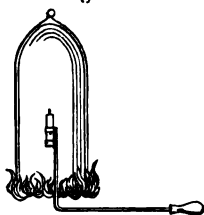


The zinc (or iron) and water are introduced by the middle tubulure. The bent tube conveys the gas to the pneumatic trough ; and by the other tube, which is open at both ends, sulphuric acid is poured in in such quantities at a time as may be necessary for evolving the quantity of gas required.

235. The contrast between oxygen and hydrogen, in their relations to combustion, may be illustrated by a simple experiment, which will be easily understood from the accompanying figure (15). Apply a light to the open end of a jar of hydrogen. A lighted taper fixed to a bent tube will answer. The hydrogen takes fire and burns at the mouth of the jar only. Push the taper up into the interior of the jar ; the light will be instantly extinguished when

immersed in the hydrogen. If brought to the mouth of the jar again, where it meets with air and the flame of the burning hydrogen, the taper will be rekindled, and if again immersed in the hydrogen, will be again extinguished. The hydrogen burns at the mouth of the jar only, because there only it meets with oxygen; for the same reason the taper will burn only at the open end of the jar. In the interior, where surrounded with hydrogen alone, not meeting with the element necessary to support combustion, it is extinguished.

Fig. 15.



II. WATER A TRUE CHEMICAL COMPOUND.

236. Water is a *true chemical compound*. It is not a mere mechanical mixture of its elements, in the way in which air is a mixture of oxygen and nitrogen. A mere mixture of oxygen and hydrogen has not the properties of watery vapour, and before they can be made to form watery vapour, they must be made to enter into chemical union by having a considerable degree of heat applied to them, by having the electric influence transmitted through them, or by being strongly compressed; none of which are at all necessary to cause a mere mixture of oxygen and nitrogen to have all the properties of air. There is a great *change* of properties, which is not the case with the oxygen and the nitrogen in the air (182).—When combined with hydrogen into watery vapour, the oxygen has lost entirely its power of supporting combustion and respiration,

although it is present in watery vapour in a far greater proportion than in air, and it is not easy to withdraw it from the hydrogen, being united by a strong chemical attraction. The hydrogen has lost entirely its inflammability. *Both have become so much altered that they are easily condensed into the liquid form, which cannot be done with either of them when separate.* There is a change of bulk, for the quantity of watery vapour formed by a certain proportion of oxygen and hydrogen occupies less space than the two gases separately. And, lastly, heat and light are produced when they combine, a sure mark of a chemical union. In these respects, water, as contrasted with air, furnishes a striking example of the difference between *combination* (chemical union), and *mixture*. See paragraph 182.

III. PROPORTIONS OF OXYGEN AND HYDROGEN IN WATER.

237. It has been mentioned, that when water is decomposed by the galvanic energy (216), one of the gases produced appears in greater quantity than the other. If the decomposition be conducted in vessels which have the tubes for collecting the gases graduated, it will be seen that the bulk of the hydrogen produced is always *exactly double of that of the oxygen*. Again, when it is proposed to form water by the union of its elements, as by exposing a mixture of oxygen and hydrogen gases to the electric influence (226), it is found that these are the proportions, estimated by measure, in which they unite; in which, if the experiment be performed in a tube or jar over water, the tube would be entirely filled with water after the conclusion of the experiment, no

gas remaining. If different proportions of oxygen and hydrogen be contained in the mixture which has the electric spark transmitted through it, a certain proportion of one of these ingredients will remain in the uncombined state. Thus, if there be in the mixture (before the combination) three cubic inches of hydrogen and one cubic inch of oxygen; after the combination, one cubic inch of hydrogen would remain in the state of hydrogen, the rest of the hydrogen and the oxygen being turned into watery vapour; the combination having thus taken place in the proportion of *two of hydrogen to one of oxygen*, although the proportions of the gases present in the mixture were *three of hydrogen to one of oxygen*. Or, to vary the experiment, if the mixture consisted of two cubic inches of hydrogen and two cubic inches of oxygen; after the combination, one cubic inch of oxygen would be found in the state of oxygen, not converted into watery vapour, while the rest would be turned into this substance, the combination, as in the case where there was an excess of hydrogen, taking place also in the proportion of *two of hydrogen to one of oxygen*.

238. But what proportion does the quantity (estimated by measure) of the two gases employed to produce watery vapour bear to the quantity of watery vapour formed? We might expect that the two parts (say cubic inches) of hydrogen, and one part (cubic inch) of oxygen would produce three parts (three cubic inches) of watery vapour; but this is not the case; they produce only two parts (two cubic inches) of watery vapour; the bulk of the product being exactly the same as that of the hydrogen employed. The watery vapour occupies

only two-thirds of the space which the materials used for its formation do ;—the particles of the two gases become closer packed together than when merely mixed with each other, undergoing what is called *condensation*.

239. It will be seen that a very large quantity of the gases (oxygen and hydrogen) produce by their union but a small bulk of water. A large quantity of watery vapour is produced, but this occupies 1696 times the space which it does when condensed into water ; a large bulk of the gases being thus required to produce even a few drops of water. Such is the very great change of bulk caused by the approximation of the particles when the repulsive principle departs from the watery vapour formed, and the cohesive power is thus enabled to exert its influence.

240. However much the bulk may vary in consequence of chemical union or the effects of heat, the weight of a given quantity of matter must always be the same. We have seen that the gases, estimated by bulk, must be in the proportion of two of hydrogen to one of oxygen, when it is wished that, after the combination, there should not be any of either gas remaining in the uncombined state: now, it has been found, that a quantity of oxygen is sixteen times heavier than the same bulk of hydrogen, from which it follows, that *one* part by measure of oxygen must weigh *eight* times as much as twice the bulk of hydrogen. This is the proportion, speaking of their weights, which the elements of water bear to each other. *Eight* grains of oxygen unite with *one* grain of hydrogen, and *nine* grains of water are produced ; had nine grains of oxygen been

mixed with that one grain of hydrogen, one grain of oxygen would have remained, after the combination, in the uncombined state; had two grains of hydrogen been mixed with the eight grains of oxygen, one grain of hydrogen would have remained, after the union, in the state of hydrogen. Also, when *nine* grains of water are decomposed by the electric power, the products are *eight* grains of oxygen, and *one* grain of hydrogen.

241. The composition of water, or rather of watery vapour or steam, may be represented in the following manner :—

*Relative Proportions necessary for forming Water
in 100 Parts of the Gases.*

	By Measure.		By Weight.	
Oxygen . . .	33·34	1	88·9	8
Hydrogen . . .	66·66	2	11·1	1
Mixed . . .	100·00	3	100·0	9
Combined . . .	66·66	2	100·0	9

242. Or, to show more clearly the relative bulks of the gases.

Composition of Water.

Name of Gas.	Weight.	Bulk.
OXYGEN . . .	8 . . .	
HYDROGEN . . .	1 . . .	
STEAM	9	

That bulk of watery vapour represented by the square figure below the line, contains quantities of oxygen and hydrogen, which, when detached from each other, would occupy a space one-half larger than the watery vapour, which is represented by the square and the half square above the line.

IV. WEIGHT OF WATER AND OF STEAM.

243. Water (distilled water) is taken as the standard in speaking of the specific gravities (relative weights) of solid and liquid bodies, its specific gravity being called 1, and other bodies having numbers attached according as they would weigh more or less than the same bulk of water. A substance twice as heavy would be represented by the number 2, one only half as heavy by the decimal 0.5. A quantity of water is 815 times heavier than the same bulk of atmospheric air; a cubic inch of water weighs 252.458 grains. An imperial standard gallon contains about 277 cubic inches, and that bulk of water weighs 10 pounds avoirdupois, or 70,000 grains. The specific gravity of air at 212 Fah. being reckoned 1, that of steam will be represented by 0.625. If air at 60° Fah. be reckoned 1, the specific gravity of steam will be 0.484. A hundred cubic inches of steam weigh 19.062 grains: and its bulk is 1696 times greater than the same weight of water.

V. EFFECT OF HEAT ON WATER.

244. Water passes into the state of vapour when exposed in open vessels, *at any temperature*, this effect being dependent on the influence of heat, the repulsive principle (55), and the amount turned *into vapour* being in proportion chiefly to the degree

of heat.—Even when in the form of ice, it slowly evaporates (turns into vapour), as is known by the ice becoming lighter and diminishing in bulk. At a certain degree of heat, indicated by the number 212 on Fahrenheit's thermometer (that used in this country), water boils, or passes *rapidly* into vapour, called steam. This degree of heat is familiarly spoken of as the "boiling point of water." *So long as the steam is allowed freely to escape, we cannot render water any hotter than this, for, at the moment at which it reaches this temperature, it becomes steam, and flies away.* This may be easily seen by placing the bulb of a thermometer in water, which is then made to boil; the temperature will gradually rise till it reaches 212°, at which point the rise will cease, and the thermometer will indicate *that temperature* during the whole time in which the boiling continues. By boiling water, however, in a close vessel from which the steam cannot escape, the heat of the water may be raised considerably above that of the usual boiling point of water. This, however, is rather a dangerous experiment.

245. Steam, when newly formed from water, is transparent and colourless, and quite invisible; but when it comes into contact and mixes with air considerably colder than itself, it is condensed, and becomes somewhat opaque, from the approximation of its particles. If water be boiled in a glass flask, with a long neck, it will be seen that the steam becomes visible only after it has issued from the flask and come in contact with the air. Between the surface of the water and the mouth of the flask, the steam is perfectly colourless and invisible. The same may be seen near the mouth of any pipe from

which steam is issuing rapidly; when it first emerges from the pipe, the steam is invisible, but becomes opaque and visible as it rises into the cold air.

246. At a low degree of heat, indicated by the number 32 of Fahrenheit's thermometer, water crystallizes, or becomes solid, forming ice. This temperature is called the "freezing point of water." When the watery vapour in the air freezes, not passing previously through the liquid form, *snow* is produced; when rain freezes before it reaches the ground, *hail* (a form of ice) is produced; when the watery vapour freezes upon some solid substance, as on grass or on the ground, *hoar-frost* is the form it assumes. When water freezes, the particles arrange themselves in particular lines or crystalline forms, in which state they occupy more space than when in the liquid form, so that ice is lighter than cold water; hence the reason why ice floats upon the surface of water; it is lighter than the water beneath. The specific gravity of water being 1, that of ice is 0.94.

247. Water in the act of freezing expands with very great force, capable of bursting even strong metallic vessels, if it be confined in them. Hence a reason why iron and leaden pipes are frequently burst in frosty weather: this frequently happens also to glass bottles containing water, and which are either tightly corked, or have narrow necks which do not permit the free expansion of the water in freezing. Many purposes are served in the economy of nature by this property of water; but the consideration of these belongs more properly to the subject of *heat*.

VI. PROPERTIES OF WATER.

248. Water, though apparently so mild and inert, is one of the most powerful chemical agents known. This depends partly on the great affinity which one of its elements, oxygen, has for other bodies; the water being decomposed when it acts in this way;—and partly on the affinities which water itself, without being decomposed, has for most kinds of bodies. Water is concerned in a very great number of chemical changes:—sometimes its formation, from the meeting of its elements, being the result of the action,—sometimes being decomposed, as it is frequently used to furnish oxygen in chemical operations,—sometimes being employed as a sort of carrier to bring other bodies into close contact, that they may act chemically with each other. Here we shall attend to the chemical action of water, considered as an agent capable of effecting changes on bodies in its entire or undecomposed state.

249. Water possesses the property of combining with a vast number of bodies. When the resulting compound is transparent, and retains the liquid form, even although it may have acquired some particular colour, the water is said to have *dissolved* the matter immersed in it, and the product in chemical language is called a SOLUTION of that matter, whether it be a solid body, as common salt, or a gaseous body, as oxygen gas; for we shall see immediately that water can unite with and dissolve gases as well as solids.

250. This is a chemical phenomenon with which every one is familiar, and is well exemplified in the

case of sugar or salt dissolved in water. But however familiar we may be with the phenomenon, we are not much in the habit of regarding it as a chemical one. Nevertheless, the cause of the sugar or salt being dissolved in the water is neither more nor less than the existence of a chemical attraction between the solid and the water, powerful enough to overcome the cohesive attraction between the particles of the solid, and cause it to pass to the liquid condition in union with the water. We have had many examples of the cohesive attraction being overcome by the repulsive principle: in the case before us, the melting of a solid in water, the particles are loosened by a different power, the chemical attraction subsisting between them and the liquid. A stone or a lump of metal remains unchanged in water, while a crystal of nitre (saltpetre) very soon becomes liquid and disappears. In the one case there is no chemical attraction between the solid and the liquid; or, if there be, it is very slight, and is prevented from taking effect by the strength of the cohesive attraction subsisting between the particles of the solid; while, in the other case, there is a considerable affinity between them.

251. Most bodies, except the metals, are a little soluble in water:—some are exceedingly soluble, as common salt and soda (carbonate of soda). At the temperature of 60° Fah., 100 parts of water can entirely dissolve 50 parts of the carbonate of soda, 100 parts of Epsom salts (sulphate of magnesia), or 36 parts of common salt (chloride of sodium). Other bodies are dissolved by water only in small quantities. One part of cream of tartar (supertartrate of potassa) requires about sixty parts of water to

dissolve it; one part of lime requires about 700 parts of water to dissolve it; one part of magnesia (carbonate of magnesia) requires about 2500 parts of water to effect its solution; and marble (carbonate of lime) is almost insoluble, cannot be dissolved at all. Hence the durability and perfect condition of many of the fine statues of antiquity.

252. When solid bodies are dissolved in water, the solution is always heavier than water. Water can dissolve a considerable quantity of common salt before its bulk is at all increased. The particles of the dissolved body insinuate themselves between the particles of the water, and the two together occupy less space than when separate; a condensation takes place.

253. In almost every case, water, when warm, can dissolve more of a solid body than when cold. Hence the theory of crystallization. Let us suppose that a pound of cold water can dissolve *half a pound* of any solid, and that a pound of hot water can dissolve *a whole pound* of the same body; then, if we dissolve a pound of it in a pound of hot water, and allow it to cool, the water while cooling will deposite in the solid state the additional half-pound which the heat enabled it to dissolve and retain in the liquid state, only a half-pound of the solid remaining dissolved when the water has cooled. From the particles of the water being loose, and the particles of the solid having free motion among them, the latter, while being deposited, will appear in that particular shape which it has a tendency to assume, and thus form a *crystal* of that substance. *Lime* and *magnesia* are the only two exceptions to the general rule that heat increases the dissolving power

of water. When cold, water can dissolve more of these than when warm.

254. Water can dissolve gases as well as solid bodies, and it dissolves or combines with a little of every gas or air with which it comes into contact. Hence all common water contains air; being in every situation much in contact with air, it dissolves part of it, causing it to assume the liquid form.* From this we may derive an explanation of a curious phenomenon, which perhaps every one has noticed. When a glass of cold water from the spring is brought into a warm room, the inner surface of the glass is soon observed to be covered with a multitude of small globules of air, adhering to the sides and gradually rising to the surface. This is the air which existed dissolved in the water, and was previously in the liquid state, being enabled to preserve this form in virtue of the attraction between water and air. But when warmed by the heat of the room, the elasticity of the air thus absorbed is increased, and disposes it to assume the gaseous condition, and, as the chemical attraction subsisting between the air and the water is not very great, it is overcome, and the air gradually separates from the water in small globules. Thus, air and water are separated from their chemical union, in consequence of the air having a greater tendency to assume the gaseous form.

255. Dr Henry examined the gas which was disengaged from some water taken from a spring at a

* In speaking of *gases* absorbed by or in solution in water, the term "gas" expresses some substance which, when uncombined, exists in the gaseous form, though in the liquid state when in union with the water.

considerable distance from the surface of the ground, and found that 100 cubic inches ($3\frac{1}{2}$ wine pints) of the water contained a quantity of gas, which when separated, occupied the space of 4.76 cubic inches, of which 3.38 cubic inches were carbonic acid, and 1.38 cubic inches air, that is, oxygen and nitrogen nearly in the proportions in which they are present in air. Carbonic acid is one of the gases of which water can absorb a large quantity. Dr Dalton has made many experiments on this subject, and finds that, in general, 100 cubic inches of spring-water yield about 2 cubic inches of gas, of which, after depriving the 2 cubic inches of about 1-10th or 1-20th of carbonic acid, and supposing the remainder to be divided into 100 parts, 38 are oxygen, and 62 nitrogen. It will be observed, that the proportion of oxygen is larger than in air; water can absorb a greater quantity of oxygen than of nitrogen; so much indeed, that the oxygen may be nearly all removed from a quantity of air, by agitating it frequently with water. When water is boiled, the gases separate from it, but it must be boiled for nearly two hours in order to expel them completely. Water, which has been deprived of air by being boiled, reabsorbs it if freely exposed to the atmosphere for some time.

256. When water is frozen, any gas which it contains separates from its chemical union with the water, assuming the gaseous form. Hence the small globules of gaseous matter which are frequently seen scattered through a lump of ice, becoming entangled between the crystals of the ice, and thus detained in it.

257. The following are the quantities of the

different gases which water can absorb. A cubic inch of water could absorb 670-cubic inches of ammoniacal gas, or 1-27th of a cubic inch of oxygen gas, and so on.

Of Ammonia, water can absorb . . .	670 times its own bulk.
... Muriatic acid,	500
... Sulphurous acid,	33
... Cyanogen,	4½
... Chlorine,	2
... Carbonic acid,	its own bulk.
... Nitrous oxide, . . . . .	.....
... Sulphuretted hydrogen . . . . .	.....
... Olefiant gas,	1-8th of its own bulk.
... Oxygen,	1-27th
... Nitric oxide,	1-27th
... Nitrogen,	1-64th
... Hydrogen,	1-64th
... Carbonic oxide,	1-64th

The above are the quantities absorbed at the ordinary pressure of the air. At higher pressures water absorbs the same *bulk* of each, but a greater quantity by *weight*, the density being increased.

258. A very simple experiment will convey an idea of the manner in which water may be made to unite with a gas. If a bottle containing a gas which is largely absorbed by water, as chlorine or carbonic acid gas, be placed perpendicularly with the mouth under water, a little water will combine with the gas at the mouth and enter the bottle: or, a little of the liquid may be allowed to enter by inclining the bottle downwards, so as to expel some of the gas; if the stopper be now introduced, and the bottle removed and well agitated, on taking out the stopper under water, a quantity of the liquid will be forced in rapidly. The water in the bottle had combined

with so much of the gas, which hence assumed the liquid form, and became very much reduced in bulk; the resistance in the interior to the atmospheric pressure, which tended to force the water into the bottle, being thus reduced by part of the gas diminishing in bulk, the water is necessarily made to rise in the bottle. By continuing in this way to agitate the liquid in the bottle, and remove the stopper under water, several times, all the gas will be speedily absorbed, and, by admitting just as much water as can absorb the whole of the gas, a strong solution of the gas will be obtained. In the case of chlorine, as water can absorb twice its own bulk of this gas, by allowing the water to rise into the bottle till it is one-third full, and then shaking the bottle well, all the gas would be absorbed, and, admitting air now and then by loosening the stopper, the bottle would be filled, two-thirds with air, the rest with the strong solution of chlorine.

259. In the same way in which air unites with water, and loses its gaseous form, water can unite with many solid bodies, lose its fluidity, and itself become solid. This is the case in the slaking of lime and the preparation of mortar, in which the solidification of water takes place.—Chemical compounds of water with other bodies are called *hydrates*, a term derived from the Greek word signifying water.

260. There is another sort of bodies in which water is almost always present in considerable abundance in the solid form—namely, crystals of the various salts,* as carbonate of soda, (the common soda of

* The term "salt" is applied by chemists to a number of bodies, besides the common salt to which this term is applied in common language. In general, salts consist of an acid in union with some

the shops), sulphate of soda (glauber salts), sulphate of alumina and potassa (alum), sulphate of magnesia (Epsom salts), sulphate of copper (blue vitriol), and many more. The water which they contain is termed their *water of crystallization*. Every one must have observed, that these salts are in the form of crystals of a regular form and semi-transparent; the water which they contain is essential to their existence in this regular shape; if part of the water be expelled by a strong heat, they become fused or melted, lose their crystalline form and their transparency, being transformed into a shapeless mass. The quantity of water which some crystals contain is very great. The crystals of carbonate of soda contain, in 300 parts of the crystals, about 200 of water; those of glauber salts contain, in 300 parts, about 170 of water; those of alum, in 300 parts, upwards of 140 parts of water.—Some salts, as nitre or saltpetre, and common salt, though in the crystalline form, contain no water of crystallization.

261. Several bodies have a very great affinity for water, and absorb and combine with it whenever they meet. Caustic potash, caustic soda, quick lime, the chloride of calcium (muriate of lime), and strong oil of vitriol (sulphuric acid) have a strong attraction for water; of these several were mentioned already as being capable of showing the presence of watery vapour in the air (127), their

compound of a metal with oxygen (an alkali, earth, or metallic oxide); and have a name indicating both the acid and the metal which they contain. Copperas or green vitriol is a "salt," called sulphate of iron, by which we understand that it consists of sulphuric acid and iron united to oxygen (oxide of iron). Cream of tartar (251), and all the substances mentioned in that paragraph and above are "salts." Cream of tartar (supertartrate of potassa) consists of tartaric acid and potassa.

affinity for it being such that they abstract it from any gas which may contain a portion of it. The most delicate test of the presence of water in the form of vapour is fluo-boric acid gas, which combines with the watery vapour, and forms dense opaque vapours, even though an extremely small portion of vapour be present. Caustic potash and soda have so strong an affinity for water, that they retain a portion in combination with them even after they have been exposed to a strong heat, and this cannot be separated except by means of some body which has a stronger chemical attraction for the potash or the soda.

262. Many crystalline salts, which contain large quantities of water, essential to their crystalline form, have so slight an affinity for the water which they contain that they part with it when freely exposed in open vessels; the water leaves them in the form of vapour, and the salt no longer retains the form of a crystal, but crumbles down to powder. This is called *efflorescence*, the salt being termed *efflorescent*. This is the case with glauber salts, phosphate of soda, and carbonate of soda. Glauber salts, if freely exposed for a sufficient time, lose in this way all the water which they contain. The rapidity with which a salt effloresces depends much upon the quantity of vapour previously in the atmosphere by which it is surrounded, and also upon the temperature. If the air surrounding be very dry, and very warm, the water will pass away very quickly from the salt; while, if it be exposed to a very damp and cold atmosphere, it will effloresce very slowly. It is heat which causes the water to pass from the solid state into vapour, and the quantity which is thus converted into vapour, and the rapidity with which

this takes place, will be in proportion to the degree of heat, and to the quantity of vapour previously in the air. Hence, to preserve a salt from efflorescing, it should be kept in a cold and damp place.

263. Substances such as those mentioned in par. 261, which become moist by attracting water from the air, are called *deliquescent*. Such are potashes; pearl ash, caustic potash, nitrate of lime, nitrate of magnesia, muriate of lime, muriate of magnesia, and others, which soon become liquid if exposed freely to a damp atmosphere; being in this respect quite opposite in their nature to efflorescent bodies. In order to preserve these bodies from deliquescing, they must be kept in a closely stopped bottle, so as to exclude the action of the moisture continually present in the air.

264. Water exists largely in all animals and vegetables, and when these are decomposed in consequence of the chemical action of their elements, which takes place when the principle of life departs from them, it is one of the principal substances which are formed. The solid matters of animals and vegetables do not in themselves constitute a large proportion of their substance; the solids are composed of innumerable cells and cavities of various kinds, filled up with different fluids, and a very large proportion of these fluids consists of water, as will be seen afterwards.

265. Water, as has been mentioned, contains many other matters besides oxygen and hydrogen, but in very small proportions compared with these; and these matters are different according to the source from which the water is procured. Sea-water is very different from the water of lakes, rivers, and springs; the water of these is also different, and

differs from rain-water, which varies somewhat from the water procured by melting snow. The great mass of all these is composed of oxygen and hydrogen, but they have all different properties, arising from the difference in the other matters associated with each. Air is of the same composition every where, even with respect to those ingredients which exist in it in such small proportion, but water varies in almost every situation from which we procure it. To understand this, let us examine—

VII. THE SOURCES OF THE DIFFERENT KINDS OF WATER.

266. The great reservoir of water, from which all other kinds of water are in the first instance derived, is THE OCEAN, an almost inexhaustible supply, when we consider that it covers about three-fifths of the entire surface of the globe. In what way is the water of rivers, lakes, springs, &c. derived from the ocean?—How is the salt water of the ocean converted into fresh water?—The water of the ocean consists of a large quantity of water, containing, dissolved in it, a small quantity of common salt, and a few other matters. Now, the water (*the pure water*, consisting solely of oxygen and hydrogen) is very readily turned into vapour, even at the ordinary temperature of the air, and very abundantly in warm weather; while the salt and the other matters, having a different relation to heat, do not readily pass into vapour, even at the highest temperature in the torrid zone. *Thus, the pure watery part of the ocean is turned into vapour and passes into the atmosphere, the salt and other matters being left behind; the sea-water being thus decomposed by*

the effects of heat upon it. The same process, namely, the evaporation of water, goes on at the surface of all bodies of water which are freely exposed, and from all solid bodies which contain water mechanically lodged in their pores as in the earth or soil, from which there is evaporation of water constantly going on ;—but the amount of watery vapour added to the air from these sources must be quite trifling, when compared with that which arises from the surface of the various seas and oceans.

267. The vapour which thus exists so largely in the atmosphere; is removed from above the ocean where it arises, conveyed to above the land, spread about, and equally diffused through the atmosphere by the influence of winds. The cold which prevails at times in various regions of the air causes this vapour to be condensed into rain or snow ; it is now heavier than the atmosphere, and descends to the ground. The water which thus falls from the clouds in the form of rain, or which is formed in such abundance in some places from the melting of ice or snow, is disposed of on the surface of the ground in many different ways, *according to the nature of the ground where it has fallen.*

268. The water which reaches the ground,—if the soil beneath it be of a porous nature, or even if the ground be rocky, the rocks being porous,—soaks or penetrates through them, often to a considerable depth, forms a sort of underground course for itself, and, if the ground be uneven or hilly, continues to drain through the earth till it arrives at some easy exit, such as some fissure or slit at the side of a hill, however small, where it discharges itself ; or, it descends through the ground till it meet some

obstruction such as would be offered to its progress by meeting with a soil of clay which is not porous, and would not permit the water to pass through it; being thus arrested in its downward progress, it accumulates, acquires force, and breaks out at some adjoining yielding point. In this manner SPRINGS are produced, and these are frequent at the sides of hills and in all mountainous regions; breaking out, however, often at a considerable distance from the spot where the water first sunk under the surface. Water is draining through the ground in this way in almost every direction, partly derived from what falls on the ground as rain or has been melted from snow, and partly from the water which must soak through the ground from the beds of rivers, lakes, &c.

269. But the water does not always fall on a flat ground, or on a soil which permits it readily to drain through it:—it often falls on ground of a clayey nature, or somewhat inclined, when it runs down along the declivities, forms streams and rivulets, wears away the ground gradually, and forms channels for itself. These streams meet with others in their course and with springs, unite with them, and constitute rivers, which gradually increasing in size and force as they advance, work a passage for themselves, till they discharge their waters into some great lake, or meet with the sea, *where they return the water to its original source.* Thus, rivers generally take their origin in elevated situations, and, though they pour such large quantities of water into the ocean, do not diminish in size, as this loss is amply made up from the melting of snow and of ice, by springs which exist in many situations where they are not exposed to view, and by rain-water.

270. The water of the ocean, therefore, does not become more and more salt and nauseous daily, in consequence of such large quantities of fresh water being removed from it in the form of vapour. This loss of fresh water by evaporation is amply made up by the large quantities of fresh water which are poured into the ocean from all the streams and rivers in the world, which sooner or later discharge themselves into this great reservoir. Thus, while heat removes fresh water from the ocean, rivers are perpetually adding fresh water to it; and the proportion of the salt to that of the water remains always the same. Near the mouths of large rivers, as might be expected, sea-water is more fresh than in the body of the ocean.

271. In other situations, the nature of the ground will not permit it to be formed into channels, nor allow the water easily to drain through. In such places we have marshes and ponds, and all the varieties of stagnant waters.

272. In other situations, the channels formed by rivers or streams have their course in the direction of some valley or ravine, which they fill up, forming lakes, discharge the superabundant water at some easy outlet, and then continue their course. Some lakes have no running streams pouring water into them, being supplied with water by springs at the bottom or sides; and some have no outlet of running water, the quantity of water lost by evaporation being nearly equal to that received from springs or streams: such are the Caspian Sea and Lake Aral in the west of Asia.—These are the sources of the chief varieties of water which require to be noticed; we shall find *that they vary considerably in chemical composition and properties.*

VIII. COMPOSITION AND PECULIAR PROPERTIES OF
THE DIFFERENT KINDS OF NATURAL WATER
FOUND ON THE GLOBE.

273. Water, as has been explained, consists of oxygen and hydrogen. *When it contains nothing besides these, it is called pure*, in the chemical meaning of this term.

274. But water is never found in nature what we may call chemically pure ; it always contains combined with it small portions of some other matters, which it has dissolved or taken up in consequence of coming in contact on all sides with such a great variety of soluble bodies. The soluble bodies which it meets being different in different situations, water must vary accordingly. Sometimes it contains such a large quantity of other matters in solution, that, though clear and colourless, and apparently pure, it may be quite unfit for many of the purposes to which we usually apply it. The different kinds of water receive names taken from the source from which they are derived. Thus, we have *sea-water*, the water of the ocean ; *atmospheric water*, including what we procure from the air in the form of rain or snow ; *river-water* ; *spring-water* ; *well-water* ; and so on. All these differ considerably from each other ; and the same kind varies in different situations.

1. *Sea-Water.*

275. The water of the ocean, of all seas, and at the mouths of rivers which discharge their waters into the sea, is characterized by a peculiar saltish disagreeable taste, which it owes chiefly to the presence of a small quantity of common salt, and a few other saline matters, which it contains in solution. *The proportion which the saline matters bear to the*

water varies considerably. The water of the Atlantic Ocean, within the tropics, contains about 1-24th of its weight of saline matters. There, from the great heat, very great evaporation must go on at the surface; and, from the great mass of water, particularly far out at sea, the influence of rivers in counteracting the effect of the evaporation by adding fresh water must be less than usual. In the Firth of Forth, the water of which was examined by the late Dr Murray, the saline matters form only 1-30th of the weight of the water. There, less fresh water is removed by evaporation, the climate being much colder; and the fresh water supplied by rivers is greater in proportion, so that the salt matters bear a smaller proportion to the whole. There are chiefly four matters contained in sea-water, *common salt* (muriate of soda), *glauber salt* (sulphate of soda), *muriate of magnesia*, and *muriate of lime*. Potash has been detected in sea-water; and it also contains extremely small quantities of two simple substances lately discovered, namely, *iodine* and *bromine*, in union with hydrogen. Disregarding all except the four first, the composition of the water of the Atlantic Ocean, as analyzed by Dr Marcet, may be stated as follows. The quantity examined was 500 grains.

Composition of the Water of the Atlantic.

Water,	478·420 grains, or 480-500ths.		
Common salt,	13·3	.....	13
Sulphate of soda,	2·33	.....	2
Muriate of lime,	0·995	.....	1
Muriate of magnesia,	4·955	.....	4
	500 grains.		500

276. The water of the Firth of Forth, examined by Dr Murray, contains in 10,000 parts, 303 of saline matter. The proportions of the different salts are as follows :—

Common salt,	220·01
Sulphate of soda,	33·16
Muriate of magnesia,	42·08
Muriate of lime,	7·84

Total quantity of saline matter, 303·09

277. The specific gravity of sea-water is in general, 1·0277, that of pure water being 1·000 ; and it freezes at about 28° of Fahrenheit's thermometer, 4 degrees lower than the temperature at which common water passes into the state of ice.

278. The water of the Dead Sea near Jerusalem, which is called also Lake Asphaltites, contains so large a quantity as one-fourth of its weight of saline matters. Its specific gravity is 1·211 ; so great indeed that a man may lie easily upon its surface without any danger of sinking ;—it contains in 100 parts, according to Dr Marcet, 10·246 parts of the muriate of magnesia, 10·36 parts of common salt, 3·92 parts of the muriate of lime, and 0·054 parts of the sulphate of lime. Its taste is remarkably sharp and bitter. The same authority states, that these ingredients also exist in the water of the River Jordan, which runs into the Dead Sea. There are many other salt lakes in various parts of the globe.

279. The ocean, then, may be said to contain muriatic acid (marine acid), sulphuric acid (oil of vitriol), magnesia, and lime : these being the ingredients of the salts which are found in sea-water.

2. *Rain and Snow Water.*

280. The vapour which arises from the surface of the various collections of water on the globe, is nearly pure, containing little besides the pure watery part (oxygen and hydrogen). The vapour which is formed from sea-water sometimes contains a little muriatic acid gas, this acid existing so abundantly in sea-water; but it is completely free from the earthy or saline matters which sea-water contains. This vapour is afterwards deposited on the land in the form of rain, dew, or snow. Hence, the purest water which can be obtained from natural sources is rain-water, collected before it has reached the ground, or that obtained by melting newly fallen snow. Even these are not very pure unless procured in the country, at a distance from large towns, or other inhabited places. But water, as we have already seen, can dissolve various gases, and as it meets with several in the atmosphere, we should expect that rain-water, and that procured by the melting of snow, should contain some of these. This is found to be the case. Rain and snow water are impregnated with oxygen, nitrogen, and carbonic acid, the matters with which the water has been in contact since it was evaporated from the body of the ocean. Rain and snow water contain a very considerable quantity of oxygen gas, and rain-water and dew contain nearly as much air as they can absorb. Rain-water collected in or near towns is always more or less impure, from dissolving the various gases and vapours, or animal and vegetable exhalations, which abound in such a neighbourhood; and when procured from the roofs of buildings is

contaminated with many impurities, from the channels through which it flows.

281. The presence of carbonic acid in water may be easily shown by the same test which is employed to discover its presence in air, *lime-water*. If a little of the water supposed to contain carbonic acid be added to a little lime-water, immediately, if carbonic acid be contained in the water, a muddiness will be produced in the liquid from the diffusion of a white powder through it (carbonate of lime), formed in the manner described in 123. Other substances than carbonic acid might produce this effect; but, *if the presence of carbonic acid be the cause of the appearance of the white powder, the addition of a larger quantity of the water containing the carbonic acid will cause the white powder to disappear, and render the liquid again clear and transparent*; for, although the carbonate of lime is extremely insoluble, it becomes soluble if a quantity of carbonic acid (besides that contained in the carbonate of lime) be in contact with it, so that *water containing carbonic acid can dissolve carbonate of lime*. We shall see immediately that this peculiarity in the effect of water on carbonate of lime gives rise to some kinds of *hard water*. Instead of rendering the liquid clear by adding more of the water containing the carbonic acid, this might be done by adding a little diluted marine acid (muriatic acid) or aquafortis (nitric acid). If these have the effect of dissolving the white powder, it is certain that it must have consisted of carbonic acid in union with the lime of the lime-water. The presence of free carbonic acid in water might also be detected by a blue vegetable infusion, as that of litmus or

cabbages, which would be turned to a red colour by the carbonic acid, but would again return to the blue tint when the liquid is heated ; the heat having the effect of rendering the carbonic acid gaseous, when it necessarily leaves the water, and the matter which caused the blue colour to pass to a red being no longer present in the liquid, the blue colour is restored. To detect an extremely small quantity of carbonic acid in water, a solution of sugar of lead (acetate of lead) must be employed, which produces a milkiness in the liquid. This is produced by the union of the carbonic acid with the oxide of lead contained in the acetate ; other substances might produce the milkiness with the acetate of lead, but if carbonic acid be the cause of it, the white powder which produces this muddiness will be removed by adding a little acetic acid (vinegar) or nitric acid, and the liquid rendered clear ; these unite with the oxide of lead, and produce a substance which is soluble in water. A solution of pure baryta may be used in the same way as the acetate of lead.

282. The presence of oxygen in water may be shown by dissolving a little green vitriol (sulphate of iron) in it ; if oxygen be present in union with the water, a yellowish powder will be deposited in the course of a day or two, whereas had the water contained no oxygen absorbed, the solution would be free from sediment. Or, a solution of green vitriol may be mixed with the water supposed to contain oxygen, when, if this be the case, the same effect will be produced,—the deposition of a yellow powder.

283. Rain-water, dew, and melted snow, are the

softest natural waters ; we shall see immediately the meaning of the term *soft* as applied to water.

3. *Spring and Well Water.*

284. All kinds of water which have remained even a very short time in contact with the ground, become impregnated with many of the various earthy and saline matters which they meet in their progress. This is particularly the case with spring and well water, which pass through strata or layers of many kinds of earth before we procure them.

285. The purest spring-water is that found in gravelly soils, or which has drained through granite, quartz, or sandy earth ; for, the matters with which the water comes into contact in such situations are very insoluble, and the water cannot take up much of them.

286. Well-water is not, in general, so pure as spring-water, because the kind of ground through which we can dig to find a well contains much soluble matter ; and hence it is that old wells have purer water than new ones. In the old ones, by the long-continued action of water, the soluble matter has been removed or gradually dissolved away, so that the proportion of these in the water must be gradually diminishing.

287. The matters generally contained in spring, well, and river water are carbonate of lime, sulphate of lime, muriate of lime, sulphates of potash and soda, muriate of soda, and sometimes a little magnesia. "In river-water," says Dr Murray, "the muriates I have found generally to form the chief impregnation, while in spring-water the sulphates and carbonates are predominant, and in the

former, the alkalis" potash and soda " are in larger quantity, while the earths, particularly lime, are more abundant in the latter."

Hard and Soft Water.

288. We may reckon two principal varieties of common spring-water—*Hard Water* and *Soft Water*. By hard water is meant water which, from the matters which it contains in solution, has the property of decomposing soap; this renders it unfit for washing, and also ill adapted for many manufactures. Hard water refuses to combine with soap and dissolve it, but decomposes it. Soft water, on the other hand, has no action on soap, except that of combining with and dissolving it, by which we are enabled to apply soap to cloths and diffuse it through them.

289. If, in its course from the situation where the water first sinks under ground to the spot where it emerges to the surface as a spring or a well, the water comes into contact with gypsum (sulphate of lime) or limestone (carbonate of lime), two very abundant minerals, it dissolves or carries along with it more or less of these earthy matters; and, if the quantity of either of these in solution in the water be considerable, we then have *hard water*.

290. Water can dissolve about 1-500th part of its own weight of sulphate of lime; but even a less proportion of gypsum than this would render water hard. According to Dr Dalton, the hardest spring-water seldom contains so much as one-thousandth part of its weight of saline matters in solution. We have seen, however, that limestone (carbonate of lime) is *insoluble* (251). How, then, can it exist

in solution in any water and cause it to be a hard water? The carbonate of lime which is in solution in the water is dissolved by the assistance of the carbonic acid contained in the water, the carbonate of lime being soluble in water containing a quantity of carbonic acid, as already explained in paragraph 281. All water which has been much in contact with the atmosphere, or which has drained through earths containing decayed animal or vegetable matters (of which most soils contain a little), contains carbonic acid; it has then the power of dissolving a little of this substance, the carbonate of lime, so abundant in the form of chalk, limestone, and marble. According to Mr Cavendish, 1200 grains of water containing carbonic acid can hold in solution one grain of carbonate of lime; while, according to Berthollet, if the water contain as much carbonic acid as it can absorb, 500 grains of it could dissolve one grain of carbonate of lime. Muriate of soda (common salt) and muriate of lime, a compound of muriatic acid and lime, are also occasionally present in spring or well water, but in general it is the presence of gypsum (sulphate of lime), which causes the hardness.

291. To discover whether any particular water be hard or otherwise, a solution of soap in alcohol (spirit of wine) is employed. By allowing some thin slips of soap to soak in spirit of wine for some time, some of the soap will be dissolved; the solution is known by the name of *solution of soap in alcohol*. If a little of this liquid be dropped into pure water, that is, water containing no free acids, lime, or other earthy matters, the liquids will remain clear and colourless after being mixed; but if added

to a hard water, the liquid will become opaque and muddy from the formation of a white curdy compound. Waters which contain an extremely small quantity of a salt of lime may be perfectly soft, that is, fit for washing, &c., and would produce a slight opacity with this test; and, in judging of the degree of hardness of a water, we must compare the degree of opacity or quantity of curdy matter produced with that in some water known to be soft. Or, by a more simple method, if a few slices of white soap be placed in a clean tumbler of the water to be examined, a judgment may be formed, from similar indications, of the quality of the water; hardness being indicated by white flakes or curdy particles around the soap.

292. Add a little of the solution of soap in alcohol to some distilled water;—no change will be perceived. Add some of the same solution to some soft water, as common spring, well, or river water, which generally contain a little lime, in union with carbonic or sulphuric acid:—a slight cloudiness will be perceived in the liquid. Add a little muriate of lime to some distilled or any common soft water, which will then resemble a hard water, and then add the solution of soap in alcohol to this liquid;—a decided change will be produced here; the liquid will turn white and curdy. The same appearance would be presented if instead of muriate of lime,* a little acid, as aquafortis or oil of vitriol, had been added.

293. If the hardness be owing to the presence of carbonate of lime, it is easily removed by boiling the

* Muriate of lime may easily be procured by adding fragments of marble to diluted muriatic acid, till they cease being dissolved.

water. The carbonic acid which (290) enables the water to dissolve the carbonate of lime, is retained by the latter by a very feeble affinity, and if the liquid be heated, the excess of carbonic acid assumes the gaseous form, and leaves the liquid, while, at the same time, the carbonate of lime necessarily becomes insoluble, and subsides to the bottom of the vessel. The water remaining is now *soft*, and may be used for washing, &c.

294. If the hardness be caused by sulphate of lime, it is removed by adding a little pearlash, or soda (carbonate of potassa or carbonate of soda). The lime of the hard water is precipitated along with the carbonic acid of the pearlash or soda.

295. To discover whether the hardness be owing to the presence of carbonate or sulphate of lime, the following tests may be applied. A solution of the nitrate of barytes will produce a white precipitate with water containing either sulphate or carbonate of lime; if the latter have been present in the water, the precipitate will be dissolved, and the liquid rendered clear on adding a few drops of pure nitric acid; if the presence of sulphate of lime caused the precipitate, this will not be dissolved by the nitric acid. A solution of sugar of lead may be used in the same way, but the nitrate of barytes is preferred.

296. Oxalate of ammonia (oxalic acid and ammonia) is the test employed to detect the presence of lime, the oxalic acid and the lime combining with each other and forming an insoluble white precipitate. Oxalic acid, even by itself, forms a useful test for detecting the presence of lime, but it is generally preferred in union with ammonia. If a crystal of oxalic acid, dropped into a glass of water, occasion

a muddiness or white precipitate, the presence of lime may be inferred.

4. *River-Water.*

297. River-water, though often muddy, from earthy particles mechanically suspended in it, is in general tolerably pure and soft, more especially when it flows in gravelly or rocky beds. Rivers are formed by the junction of running streams and springs; the former, being much made up of melted snow and rain-water, are very soft, and the water of the springs, though often very hard, from containing much earthy matter, when it emerges from the ground, gradually deposits a considerable quantity of its earthy ingredients when it has flowed for some time in contact with the air, while it absorbs a quantity of air, with which it is now so much in contact. A striking illustration of the effects produced on water containing earthy or saline matters in solution by exposure to the atmosphere has been recorded by Mr Parkes. A shallow stream of water which flowed through the grounds attached to a print-work was so impure as to be unfit for many of the purposes for which water was there required; but when the same stream had passed this work, and reached another of the same kind at a considerable distance, and belonging to the same proprietors, it was fit for most of their operations.

298. The water of the river Clyde contains in an imperial pint (about $34\frac{1}{2}$ cubic inches), weighing about 8750 grains, 1.04 grains of saline matters (consisting chiefly of muriate of magnesia, sulphate of soda, and common salt), 0.1 grain of silica or *flinty earth*, and 1.35th of its bulk of gases, of which

1-20th is carbonic acid, and the remaining 19-20ths common air.

299. All that is necessary in order to render river-water fit for use is to filter it. This is rather a mechanical than a chemical operation, and is done by causing the water to pass through several layers of sand or stony matter, which intercept the muddy particles as the liquid passes through. Filtering-stones, made of some porous material, such as sand-stone, and hollowed out so as to be capable of containing a considerable quantity of water, have sometimes been employed to purify water. Compressed sponges have also been used for this purpose. Sand and charcoal form the chief elements in the construction of the filters now so much employed for purifying water, the powdered charcoal acting not only mechanically in detaining any muddy particles, but having a chemical effect in sweetening the water (rendering it fresh) if it be at all tainted, or even in retarding its putrefaction, if it have any tendency that way.

5. Water of Pools and Marshes.

300. Water from stagnant pools and marshes is of a very bad quality : this arises from the putrefied animal and vegetable matters with which such collections of water abound, the soluble parts of which are taken up and retained by the water. In marshes and ponds, the simpler tribes of vegetables thrive luxuriantly : in course of time they decay like other organized beings ; the water dissolves many of the new matters produced by their putrefaction, and acquires noxious properties ; and when the heat of the sun evaporates the water, some of these matters

are rendered gaseous along with it, mix with the air of the place, and give rise to those marshy exhalations or effluvia (marsh miasmata as they are called) which render such situations so unhealthy, and warm countries produce so many pestilences. It was in the vicinity of a marsh, abounding in putrid vegetable matter, that the cholera broke out in India.

IX. METHOD OF PURIFYING WATER.

301. In order to procure pure water from a common spring or river water, there are two kinds of substances which must be got rid of before it is chemically pure—the gaseous matters which it contains, and the earthy matters. The air or other gases are easily dismissed by boiling the water for a short time, the vapours which arise being allowed to escape. They are thus separated from the water on the same principles on which the air is separated from spring-water when a glass of it is brought in a warm room (254). The gaseous matters, being more volatile, are all expelled before much of the water has passed into steam.

302. But the earthy matters are separated in a different manner; the water is obtained free from them by the process of *distillation*. After the water has been boiled to expel all the gases which it may have contained, we continue to boil it, but cause the vapour or steam which comes away from it to pass into another vessel in which it returns to the state of water. The heat applied to turn the water into vapour cannot convert into vapour the earthy matters which the water holds in solution—they remain behind. Thus, by allowing the first vapours to pass away altogether, the gases are got rid of. The

next vapours which come away are collected and condensed—they are the pure watery part. About a third of the water is to be left in the vessel along with the earthy matters, and it will be seen that this water which remains behind is somewhat opaque and muddy, or at least not so clear and pellucid as the water condensed from the steam.

303. The separation of the pure watery part of the ocean in the form of vapour from the saline matters, and the condensation of these into rain or dew, is a natural process of distillation carried on slowly, but on a very large scale.

304. If not carefully preserved from the access of air, distilled water will soon absorb oxygen, nitrogen, and carbonic acid. It must be preserved in a closely-stopped bottle, quite full of the liquid.

305. Pure water obtained in this manner has not that sparkling appearance which water impregnated with gases presents when poured from one vessel to another, nor is it so pleasant to the taste; it is insipid and almost nauseous. Every one knows the mawkish taste of boiled water. This arises from the expulsion of the gases. Distilled water wants that pungency and agreeable sharpness which spring-water possesses.

306. These properties, which render common spring-water, whether hard or soft, so agreeable as a beverage, it owes partly to the gases which it contains, and partly to the saline and earthy matters. Without these it would entirely want that freshness which gives it such an agreeable relish: these gases and saline or earthy matters constitute a sort of natural seasoning to the water, which renders it palatable.

307. Pure distilled water has no smell or taste, is lighter than water which contains other matters in solution, is more penetrating, that is, wets bodies more speedily and more thoroughly than when it contains earthy matters, and produces no precipitate, discoloration, or opacity with solutions mentioned in paragraphs 281-2 and 291-6, and which are used for detecting the various bodies likely to be present in water. Even common water gives indications of various matters with many of them—pure water with none.

X. MINERAL WATERS.

308. In general water takes up such small quantities of the matters which it meets in its progress through the ground, that its appearance, taste, and other qualities are not much affected. This is the case in well, spring, and river water, as generally met with.

309. But, in some situations, the water becomes so strongly impregnated with various matters with which it has been in contact, such as salts of iron, common salt, Epsom salts, carbonate of lime, sulphuretted hydrogen or carbonic acid gases, &c., that its taste, colour, chemical properties, and effects on animals are very obviously affected. Such waters are termed *mineral waters*, or *medicinal waters*. Other waters are characterized by being warmer than the surrounding earth and atmosphere: these are called *hot springs*, and these also always contain various matters in solution which distinguish them from common water.

310. Many different substances are found in *mineral waters*. Of the gases, carbonic acid and

sulphuretted hydrogen are the most common ; but nitrogen and sulphurous acid are occasionally met with. The carbonates of soda, lime, magnesia, and iron ; the sulphates of the same bodies ; the muriates of soda, lime, and magnesia—frequently occur in mineral waters ; and in some of these, though rarely, hydriodic acid, fluoric acid, potash, strontia, lithia, silex (flinty earth), sulphate of alumina, and muriate of manganese, have been detected.*

311. According to their properties and the leading ingredients which they contain, mineral waters may be divided into four kinds,—1. The *acidulous* or *carbonated* ; 2. The *sulphureous* ; 3. The *chalybeate* ; 4. The *saline*.

1. *Carbonated Waters.*

312. Carbonated or acidulous springs are those, the water of which contains a considerable quantity of carbonic acid. From the presence of this ingredient they have a sharp, somewhat acid taste ; and present a sparkling appearance when poured from one vessel to another, arising from the particles of the acid passing into the gaseous form and escaping from the water. This escape of the carbonic acid takes place when the water is heated, or exposed to the air, so that it soon becomes like common water, losing the pungent taste and sparkling appearance.

* This is a long list of bodies, the nature of which has not been explained, but beginners need not encumber their memories with the names of all these substances ; the following are sufficient to attend to at present, and most persons are somewhat familiar with them, as they are abundant and in common use every where :—*carbonate of soda* (the common soda of the shops), *carbonate of lime* (chalk, marble, and limestone), *sulphate of soda* (glauber salt), *sulphate of lime* (gypsum), *sulphate of magnesia* (Epsom salt), *muriate of soda* (common salt). See note, page 181.

The carbonic acid may be completely expelled by boiling the water. The methods by which such waters may be distinguished have been mentioned in paragraph 281.

313. The most celebrated springs of this sort are those of Seltzer, Pyrmont, Spa, and Carlsbad. But all of them contain a considerable quantity of saline matters besides the carbonic acid.

314. As a specimen of the general composition of these waters, the following view of the composition of the Spa water is given.

SPA WATER.

Specific gravity,	.	1.001
A wine pint yields, of		
Carbonic acid gas,	.	13 cubic inches.
Carbonate of soda,	.	1.5 grains.
..... magnesia,	.	4.5
..... lime,	.	1.5
Common salt,	.	0.2
Oxide of Iron,	.	0.6
8.3 grains.		

315. The same quantity of the Pyrmont water yields 26 cubic inches of carbonic acid gas, and contains 30 grains of saline matters, of which 10 grains are carbonate of magnesia (commonly called magnesia), 5.5 are sulphate of magnesia (Epsom salts), and 8.5 sulphate of lime. The same quantity of the Seltzer waters contains 29 grains of saline matters, of which 17 grains are common salt; and yields 17 cubic inches of carbonic acid gas. The Carlsbad waters yield, from a wine pint, only 5 cubic inches of carbonic acid. They contain about ten or twelve

different salts, and a little silica or sandy earth, being of a very compound nature.

316. The carbonated waters are stimulant in their action on the human frame, and, according to Dr Duncan, are "even capable of producing a certain degree of transient intoxication."

2. *Sulphureous Waters.*

317. The sulphureous waters are characterized by a peculiar fetid odour, resembling that of putrid eggs, which they owe to the presence of sulphuretted hydrogen in the water. This substance (a gas when uncombined) consists of sulphur and hydrogen, and when water containing this compound substance is exposed freely to the air, the oxygen of the latter unites with the hydrogen of the sulphuretted hydrogen, while at the same time the sulphur, having lost the hydrogen, is deposited as a yellowish sediment; the sulphur, at the ordinary temperature of the air, always assuming the solid form when not in chemical union with other bodies.

318. Waters of this kind are also distinguished by rendering metallic silver black, or by causing a brownish black precipitate with a solution of sugar of lead (acetate of lead), or a solution of lunar caustic (nitrate of silver), arising from the union of the sulphur with the metallic silver or metallic lead. Like the carbonic acid of the carbonated springs, the sulphuretted hydrogen is rendered gaseous and expelled if the water be boiled.

319. The most notable springs of this kind are those of Aix-la-Chapelle, Harrowgate, and Moffat. The following is the composition of the

HARROWGATE WATER.

One wine gallon yields, of	
Sulphuretted hydrogen gas, . . .	6·4 cubic inch
Carbonic acid gas,	5·25
Nitrogen gas,	6·5
Carburetted hydrogen gas, . . .	4·65
	22·8
And of	
Common salt,	735· grains.
Muriate of lime,	71·5
..... magnesia,	43·
Bi-carbonate of soda,	14·75
	864·25

320. The Moffat water contains nitrogen, bonic acid, sulphuretted hydrogen, and a little mon salt. At Cheltenham and Leamington are also springs which contain a little sulphur hydrogen.

3. *Chalybeate Waters.*

321. Those waters are termed chalybeate and contain iron in such quantity as to form one of leading ingredients. The term "chalybeate" is derived from the Latin word *chalybs*, signifying "iron," "steel." The iron is united to oxygen, forming an oxide, which is, by itself, insoluble; but in chalybeate waters the oxide is in union with carbonic, sulphuric, or carbonic acid, generally the latter. When a water of this kind is freely exposed to the air, so much of the oxide of iron unites with the oxygen of the air (thus acquiring an additional supply of oxygen), leaving, at the same time, the acid with which it was previously

union, and forms an insoluble substance (peroxide of iron). This is the cause of the brownish-yellow deposit observed at the sides and bottoms of such springs.

322. Chalybeate waters are distinguished by giving a black precipitate with an infusion of galls. They have an inky, somewhat astringent taste; and always contain a number of ingredients besides the carbonate of iron, such as those which are found in the saline waters.

323. The most celebrated chalybeate waters are those at Tunbridge, Brighton, and Cheltenham, and there is also one at Harrowgate.

4. *Saline Waters.*

324. This includes most mineral springs which do not belong to any of the preceding divisions. They generally contain some of the following salts:—sulphate of lime, sulphate of magnesia, and sulphate of soda, carbonate of lime, carbonate of magnesia, and carbonate of soda, and muriate of lime, muriate of magnesia, and muriate of soda.*

325. The most noted saline springs are those of Epsom, Cheltenham, Bath, Bristol, Buxton, Piteathly, Dunblane, and Seidlitz. The following is the composition of the Cheltenham waters:—

CHELTEMHAM WATER

Contains, in a pint,

Sulphate of soda,	.	.	15· grains.
..... magnesia,	.	.	11·
..... lime,	.	.	4·5
Muriate of soda,	.	.	50·

* This is common salt, now termed *chloride of sodium*.

326. The composition of the Dunblane and Pitcaithly waters, as analyzed by Dr Murray, is as follows:—

DUNBLANE WATER

Contains, in a gallon, .

Muriate of soda,	.	168.	grains.
..... lime,	.	166.48	
Sulphate of soda,	.	29.6	
Carbonate of lime,	.	4.	
Oxide of iron,	.	1.36	

PITCAITHLY WATER

Contains, in a gallon,

Muriate of soda,	.	101.6	grains.
..... lime,	.	161.6	
Sulphate of soda,	.	7.2	
Carbonate of lime,	.	4.	

327. Some springs are characterized by containing a considerable quantity of siliceous earth (flinty earth) in solution ; but these are not common. The most noted are the boiling springs of the Geyser and Rykum in Iceland, and some hot springs in India. They contain soda also, which, along with the high temperature, assists to render the siliceous earth soluble ; this substance being very insoluble when no alkaline matter is present.

328. There are many other varieties of water found on various parts of the globe, such as *petrifying springs*, which penetrate the pores of vegetable and animal substances placed in them, and deposit earthy or stony particles (generally siliceous earth),

which are arranged in the same way as those of the former substances, and preserve their general form ; there are many waters of this kind. The rivers Danube and Pregel, in the course of ages, convert in this manner into petrifications the stakes of wood which are placed in them : there are also *encrusting springs*, which deposit the earthy particles they contain in the form of a crust around any substances placed in them. These earthy particles are carbonate of lime, held in solution by carbonic acid, which leaves the water when it becomes exposed to the air, and then the carbonate of lime is precipitated. Similar changes must have gone on in ancient periods, when the substance of the animals which gave form to the organic remains of the geologist was removed, and calcareous or siliceous particles substituted.

329. There are springs or lakes containing boracic acid, alum, sulphuric acid (oil of vitriol) ; some contain copper in solution ; in others soda or carbonate of soda is found, these being called alkaline ; and others are characterized by being warmer than the surrounding earth and atmosphere. Such are the springs in Iceland, which present the singular phenomenon of natural fountains of hot water in a small island, the shores of which are surrounded with ice.

330. The waters of Carlsbad, Aix-la-Chapelle, Bristol, Bath, Buxton, Matlock, and those in Iceland, are the most noted of the hot springs in Europe ; their temperature varies from that of 68° Fahrenheit's thermometer to that of boiling water (212° Fah.), which is the temperature of some of the springs in Iceland.

XI. USES OF WATER IN NATURAL OPERATIONS.

331. The action of water in the economy of nature is dependent on its relation to heat ; on its disposition to unite with some earthy matters and form hydrates ; on its dissolving power ; on its power of penetrating and draining through porous rocks and earth ; and on its invariable tendency to flow from a higher to a lower situation, by which means matters dissolved or mechanically suspended in it, are transported to a distance. When water saturated with saline matters cools, or diminishes in quantity from evaporation, so much of the saline matter will be deposited in the solid form. When from some chemical action an insoluble solid is formed in water, the solid will subside to the bottom in fine powder. When water containing solid matter mechanically suspended in fine powder becomes still, the solid matter will subside and form a sediment at the bottom. In considering the relation of water to geological phenomena, either in former periods or at the present time, it is important to bear in mind that in almost all cases the quantity of any solid which it can dissolve increases with the temperature, and that the quantity of gaseous bodies which it can absorb increases with the pressure.

332. As an illustration of the uses of water, it may be mentioned that the vegetable creation is dependent for support on the dissolving power of this liquid. Plants take in their food by their capillary rootlets only in the fluid form, and it is water which dissolves it and gives it this form. Water also aids in the decomposition of the organic matters found in the soil, from which plants derive

their main support. In relation to the animal creation the uses of water are obvious. The most interesting actions of water will be examined in the next chapter.

RECAPITULATION.

333. Water exists every where, and is capable of assuming a great variety of forms; as commonly met with, water is a very compound substance, but consists chiefly of two ingredients, the others existing in it in a very small proportion. I. Water is composed chiefly of two substances, which assume the gaseous form when separated from each other, *hydrogen*, an inflammable body, but which cannot support the combustion of other bodies, and *oxygen*, which has the latter property, but cannot itself be made to burn; discovered by Cavendish. II. Estimated by weight, these elements exist in water in the proportion of 8 of oxygen to one of hydrogen; estimated by measure of the exact quantities of the gases required to produce a certain quantity of watery vapour, without either gas being in excess and remaining in the uncombined state, 2 of hydrogen combine with 1 of oxygen; and, in becoming watery vapour, these become condensed into 2-3ds of the bulk they occupy separately—the bulk of the hydrogen. III. Water is a true chemical compound, not a mere mixture of its elements. IV. Water is turned into vapour by heat, and into a solid (ice) when much heat is removed from it. V. Water can combine with a vast number of bodies, solids or gases, and make them pass to the liquid state. By its dissolving power, it separates the particles of bodies from each other, reduces them to a minute

state of division ; and, by bringing their particles close contact with each other, enables them to exert their chemical affinities for other bodies. Water also unites with solid bodies, itself becoming so and it enters into the composition of crystals, &c. of animals and vegetables. VI. All the water the earth arises, in the first instance, from the ocean in the form of vapour, which becomes deposited on the land as snow, rain, or dew, and, according to the nature of the ground on which it falls, gives rise to rivers, springs, or lakes. VII. In different situations water has different properties, from the various matters which it meets and dissolves being different in different places. The leading varieties are, sea water (containing common salt, &c.) ; rain water ; snow water ; spring and well water ; hard water, this property arising from the presence of sulphur or carbonate of lime ; river-water ; water of ponds and marshes. VIII. Pure water is obtained by boiling common water to expel the gases, and by distilling it, to separate the pure watery part from the earthy matters, the former arising in vapour, and being collected in a receiver. From the absence of the gases and earthy matters, pure or distilled water is insipid and mawkish, unfit to be used for drink. IX. Waters become in some places so strongly impregnated with various matters which they dissolve, that their taste, colour, and chemical properties are affected in a marked degree, and they acquire at the same time medicinal properties. Of these there are four kinds, the carbonated, which contain carbonic acid as their most characteristic ingredients as the waters of Seltzer, Spa, Pyrmont, and Carlsbad ; the sulphureous, which contain sulphuretted

hydrogen, as the waters of Aix-la-Chapelle, Harrowgate, and Moffat; the chalybeate, which are distinguished by containing iron, such as the waters at Tunbridge, Brighton, Cheltenham; and the saline, which are characterized chiefly by the presence of common salt, Epsom salt, glauber salt, muriate of lime; the most noted of these are the waters at Bath, Bristol, Buxton, Epsom, Cheltenham, Pitcaithly, Dunblane, and Seidlitz.

CHAPTER V.

THE MINERAL KINGDOM.

334. When we speak of the composition of the solid materials of the earth, it must be borne in mind that we are acquainted only with a very limited portion of the earth. In detailing our knowledge of the composition of the globe, we mean only that part of it immediately under our feet. This is sometimes called the "crust of the earth;" by this we are not to understand that there is a kind of crust, different from and enveloping some interior matter, but merely consider it as a convenient term applied to the parts at the surface.

335. The mean diameter of the earth is about 7912 miles, its polar diameter being 7899·17 miles, and its equatorial diameter 7925·64 miles. The earth is thus a spheroid with a difference of 26·4 miles between its two diameters. The mean radius of the earth (distance from the centre to the circumference) is 3956 miles. This spheroidal form is considered to be owing to the centrifugal force at the

equatorial regions caused by the earth's revolution on its axis ; and from the distribution of land and water, and the arrangement of the rocks, there is reason to infer, that when assuming this form the earth was entirely, or in the great mass of the interior, in a fluid state.

336. From this argument, as well as from some astronomical and geological considerations, and the constantly increasing temperature as the depth is greater (58), there are some grounds for the opinion that part of the interior of the earth is still in the fluid state, being retained in that state by the great heat which is believed to prevail there ; and that the globe is a mass of heated matter cooling slowly.

337. Of the earth's surface, three-fifths are occupied by the ocean. Its average depth is estimated at about five miles. The tops of the highest mountains are about five miles above the level of the sea. Our knowledge of the crust of the earth derived from deep pits and mines would extend but a very short way towards the centre, perhaps 1-6000th, a little more than half a mile. But the volcanic convulsions which have at various times raised up rocks from great depths, and brought their fractured edges to the earth's surface, have exposed to our view in some situations beds of rock which have been several miles below the surface ; and it is next to certain that at the places from which these rocks have been removed beds of similar rocks spread for considerable distances around. It may almost be calculated, from the extent of many exposed layers of rocks, that in some places strata are thus exposed which have once lain at a depth of upwards of ten miles.

338. When we look around us at the mineral bodies which lie uppermost at the surface of the earth, we perceive that they present a very diversified appearance; but on considering them attentively, it will be found that they can be arranged in classes or divisions, each of which classes embraces a number which have several common points of resemblance, and all of which differ in some leading character from those in every other class or division. At first sight, we shall be disposed to arrange them in four divisions, *rocks*, *stones*, and the powdery matters familiarly known by the names of *earth* and *sand*. This division, however, implies a very limited acquaintance with the properties of the different mineral bodies. A convenient division of the various objects which compose the mineral kingdom is that into—rocks and stones—sand—earth—native metals—native salts—and combustible minerals. The more correct arrangements will be given afterwards.

I. GENERAL CHARACTERS OF ROCKS AND STONES,
SAND, EARTH, NATIVE METALS, NATIVE SALTS,
AND COMBUSTIBLE MINERALS.

1. *Rocks and Stones.*

339. Rocks and stones are hard, dense, and heavy; their particles cohere firmly together; they are little altered by the application even of a considerable heat, and cannot be easily melted (are almost infusible); they are incapable of being burnt in the way in which charcoal or sulphur burn; they are not, in general, much (or rapidly) altered by the action of water, being almost insoluble; they are

brittle, and can easily be reduced to a fine powder by pounding them; they cannot be drawn out into wires, or beat into thin plates or leaves like the metals. Such are the characters of the various kinds of stones of which mountains are composed, the beds of which are under the surface of the earth, stones of all kinds, including both common stones and the precious stones, and, in short, every thing commonly known by the name of minerals. We have examples of these in granite, slate, flint, limestone, rock-crystal, and all the gems, except the diamond, which is distinguished by one important character from the minerals just mentioned. The average specific gravity of the leading rocks found in the crust of the earth is 2.5. That of the whole earth is estimated at 4.

2. *Sand.*

340. The mineral substance which is most abundant, next to rock (that under the surface of the mountain), is perhaps SAND, as that of the shores, which in many places forms the bed of the ocean, and also forms beds in many parts of the land, often of considerable depth and extent. The particles are generally sharp and hard, and of various sizes, large, not being at all soft or friable. It is divided into two kinds, *siliceous* and *calcareous*.

3. *Earth.*

341. EARTH, such as is found in our fields, constitutes the *soils* which give nourishment to the various crops of vegetables which we rear on it. It is a very abundant substance. This earth, for the most part, consists of a fine, light, softish powder, aggregated into lumps by the adhesive nature

particles when moistened, and more or less mixed with gravel and stones.

342. These, rocks, stones, sand, and earth, compose by far the greater part of what we are acquainted with of the crust of the earth. There are a few other kinds of bodies which belong to the mineral kingdom of nature, namely, *metals*, *salts*, and *combustible minerals*.

4. *Native Metals.*

343. There are found occasionally in various places, mineral bodies which are characterized by being exceedingly heavy; by being more or less hard, and at the same time very tough or tenacious, so that they cannot in general be reduced to powder; by being malleable, so that they can be beat out into thin plates or leaves; by being ductile, so that they can be drawn out into fine wires; by being more or less bright and resplendent, so that they can be polished and made to acquire a clear shining surface, when they reflect light powerfully; by being opaque, never transparent; by being reduced to the liquid state (fused) by the application of heat, returning to the solid condition when they cool; and by being perfectly insoluble in water. Such bodies are called *metals*. They are generally procured in the metallic state from other bodies by artificial operations; but a few are found in nature, as gold, platinum, quicksilver, silver, copper, antimony;—found in this state in nature, they are termed NATIVE METALS.

5. *Native Salts.*

344. There are other minerals found in nature, which differ considerably in their characters and

properties from either of the preceding kinds ; but they are rare. They are found in regular shapes or forms called *crystalline*, are not nearly so hard as rocks and stones, yielding readily to any force that may be applied ; they are very soluble in water, and are readily fused or melted by the application of a considerable heat. Nitre or saltpetre (nitrate of potassa), green vitriol (sulphate of iron), rock-salt (muriate of soda), sal-ammoniac (muriate of ammonia), borax (tincal, baborate of soda), alum (sulphate of alumina and potassa), natron (carbonate of soda), are examples of this class. They are called salts, because they bear a considerable resemblance to common salt in their composition and properties (see note on composition of salts in page 181) ; and they are termed **NATIVE SALTS**, because they are found ready formed in the earth, to distinguish them from those bodies of a similar nature,—such as the bichromate of potassa, or ferrocyanate of potassa,—which are formed only by artificial processes.

6. *Combustible Minerals.*

345. A few mineral bodies are characterized by being inflammable. Such are sulphur, mineral charcoal, mineral pitch or bitumen, the diamond, plumbago or black lead, amber, and all the varieties of coal. The whole of these combustible minerals, with the exception of sulphur, contain charcoal.

346. These five divisions include all the various kinds of mineral bodies known ; some of these divisions, however, resemble each other so much in

their chemical composition and properties, although they differ somewhat in their mechanical condition, that they may be safely included in one class.

347. This is the case with rocks, stones, and earth; however much they differ from each other in external appearance and mechanical properties; though rocks are hard, dense, and firm, while earth is loose and soft, they are, chemically speaking, of the same nature. Stones are merely broken bits of rocks, and earth is the powder formed by the mouldering and mixing of various stones and rocks, the cohesion of their particles being destroyed by various causes. Rocks and stones are often observed crumbling down gradually to the state of earth, and, although ages are necessary to produce any very marked change upon rocks, still this change is going on, and has been in progress since their formation. Earth is rock reduced to powder by a slow but sure process of nature: we are not to regard them as chemically different.

348. Earth was one of the elements of the ancients: by this, however, we are to understand that they reckoned it one of the general forms of matter, for they must have been acquainted with striking differences between various kinds of earthy bodies. Modern chemistry has shown that rocks and earth are substances of a very complex nature, containing a great many different ingredients, although they appear so simple in their composition. Since this has been ascertained, the word EARTH has had a double meaning, being applied by chemists as a general term expressive of a particular class of compounds, of which rocks and common earth are found to be composed, and being used in popular language

to express the matter of earth or soils, without any reference to the ingredients of which they are composed.

349. The native metals and native salts (with the single exception of *rock-salt*) bear a very small proportion indeed to the mass of mineral bodies which form the crust of the earth; combustible minerals, including coal, are more abundant; but the quantity even of these is as nothing when compared with the prodigious quantities of rock, sand, and earth. It is these that form the main bulk of those parts of the earth which are open to our view; we shall therefore inquire first into the chemical composition of these substances, applying to them, since earth is merely pulverized rocks, the general name of *earthy matters*.

II. EARTHY MATTERS CONSIST, IN GENERAL, OF SOME SUBSTANCE OF A METALLIC NATURE IN CHEMICAL COMBINATION WITH OXYGEN, FORMING AN OXIDE; THIS OXIDE BEING, IN SOME CASES, IN CHEMICAL UNION WITH SOME BODY OF AN ACID NATURE.

350. The characters by which metals are distinguished have been mentioned in paragraph 343. These bodies are not often found native; in the state in which they exist in the earth, they are generally combined with some other kind of matter, as sulphur or oxygen. In this condition, they form the bodies well known by the name of *the metallic ores*, from which the metals so much used in the arts, &c., as iron, tin, copper, zinc, lead, are procured. It will throw some light on the nature of earthy matters to take a cursory view of the leading differences between metals and their ores.

351. The metals, it is well known, are tough and firm, their particles adhering firmly to each other; but the metallic ores are quite of a different character; they have a stony appearance, and they are perfectly brittle, being easily reduced by pounding to the state of an earthy powder. Such is the effect produced upon the metals by being combined with sulphur or oxygen. The iron of this country is extracted from a stony matter called *clay iron ore*, consisting chiefly of iron, oxygen, and charcoal. Metallic copper is procured from a stony matter called *copper pyrites*, and consisting of metallic copper in chemical union with sulphur. Metallic zinc is obtained from a mineral called *calamine*, consisting of zinc, oxygen, and charcoal, or from *blende*, which consists of sulphur and zinc. Antimony and lead are extracted from stony matters consisting of these metals united with sulphur; and quicksilver exists in nature chiefly in union with sulphur, forming *cinnabar*, from which this metal is extracted.

352. That the metals form brittle earthy matters when united to oxygen, may be shown by a few very easy experiments with zinc, lead, or iron. If a few fragments of zinc be placed in a crucible or in an iron ladle, and exposed to a considerable heat in a furnace, or in an open fire, they will be melted, and will soon begin to burn with a bluish-white flame; if the zinc be examined while it is burning, it will be perceived that it is becoming converted into a white earthy powder, very light and easily blown away. If the white powder be removed from the surface of the metallic zinc as fast as it is formed, the whole of the zinc will be turned into a matter

of a powdery nature, much resembling cream tartar in its appearance, and having much of the consistence and general properties of *earth*. This change has been effected by the union of the metallic zinc with oxygen furnished by the air. However much the zinc might be heated, no earthy powder would be formed were the access of oxygen prevented. The same conversion of a hard tough metal into a loose earthy powder may be seen in treating metallic lead in a similar manner. Litharge (a yellow scaly matter) or red lead (an earthy powder) will be formed, according to the quantity of oxygen which combines with the metallic lead. When metallic copper is treated in this manner, a crust of a black earthy matter is formed on its surface. All these earthy matters are compounds of the metallic body with oxygen derived from the air. This transformation of tenacious metallic bodies into brittle substances of an earthy nature is observed even at the usual temperature of the atmosphere. When iron is freely exposed to air and moisture, it is destroyed, that is, it loses its metallic properties; it rusts, as is well known,—this operation consists in the conversion of those parts of the metal which are exposed into a reddish-brown earthy matter which peels off in brittle scales, entirely destitute of that strength and toughness which is observed even in the finest and most delicate iron wire. This change is similar to those already described,—consisting essentially in the formation of an *oxide*, by the union of the metallic iron with the oxygen of the air.

353. All the common metals, then, can be converted into brittle or powdery earthy matters by uniting with oxygen, being then called *metall*

oxides ; many of the ores from which they are procured are metallic oxides ; and they generally exist in nature in the form of an earthy or stony looking matter, having much of the external appearance and mechanical properties of common rocks and stones. *We shall find that these rocks and stones, and what we "call common earth," bear a very close analogy, in many points, to metallic oxides.*

354. For a long period, **SILEX** or flinty earth, **ALUMINA** or earth of clays, **MAGNESIA**, and **LIME**, were well known to chemists as earthy substances, differing considerably from each other in their properties. By the chemical analysis of mineral bodies, such as rocks of various kinds, stones, sand, earth (not including metallic ores, native metals, native salts, and combustible minerals), it was found that, whatever operations they were subjected to, they were finally resolved into one or more of the above-mentioned substances, some minerals consisting of only one of these, others containing several of them ; and being therefore considered as the elements of which mineral substances were composed, these received the name of **EARTHS** (348). These earths, like the minerals which they compose, are opaque bodies, possessed of little lustre, light, and of a loose texture, not combustible, not melted except by a most intense heat, and hardly soluble in water.

355. These four substances form the great mass of the earthy matters which constitute the crust of the globe. Other substances of a somewhat similar nature have lately been discovered, namely, baryta, strontia, glucina, yttria, thorina, and zirconia. These exist in the earth in very small proportion compared with the four mentioned above.

356. It had been observed frequently that metallic oxides,* such as the oxide of zinc, (the oxide of lead (352), or oxide of iron (subsequently known to consist of oxygen and a metal, because they could be formed from these two ingredients because these metallic bodies are procured, when oxygen is abstracted from them), bore a considerable resemblance in their appearance and general properties to the earths; and from this it was conjectured by some that they are similar in composition that the earths are metallic oxides. Several attempts to prove the correctness of this conjecture were made by the older chemists, but were unsuccessful, from the want of those means of chemical investigation possessed by modern chemists; these bodies were therefore considered simple in their nature.

357. It was reserved for the late celebrated Humphry Davy to establish, by a series of happily contrived experiments which have immortalized his name, the truth of the supposition *that the earths are compounds of a metallic body with oxygen-metallic oxides*. These metallic bodies with which oxygen is united in the earths resemble the common metals in many of their properties, and are regarded as belonging to the class of metals, so that the earths are to be considered analogous in their composition to oxide of iron or oxide of lead. These peculiar metals have the shining lustre, opacity, and malleability of the common metals.

* The term "metallic oxide," in its literal meaning, applies to any compound of a metal with oxygen; it is in general, however, restricted to combinations of the common metals, as iron, zinc, silver, with oxygen.

358. This discovery is justly considered one of the most brilliant of those which, from their importance and the effect they produce on the science, stand forth and mark out successive epochs in the progress of modern chemistry. The discovery of substances of a metallic nature in earthy bodies which were formerly reckoned simple, was first made with the alkalies, potassa and soda, the pure earthy matter of which Sir Humphry Davy found to consist of peculiar metals united to oxygen; and, by means of particular processes, he separated the oxygen from the metal, and obtained the latter in the metallic state. The metal which he procured from potassa he called *potassium*.

359. In the present nomenclature of chemistry, the termination *um* indicates that the substance is of a metallic nature; and though some metals, as iron, silver, copper, have not terminations of this kind to their English names, their Latin names all terminate in *um*, as *ferrum*, *argentum*, *cuprum*.

360. The method by which Sir Humphry Davy proved the composition of potassa was similar to that described in paragraphs 215—216, for showing the composition of water. The potassium and oxygen are united by a powerful chemical affinity, which must be overcome in order to procure the potassium by itself. The decomposing power employed to separate the potassium and the oxygen was the galvanic energy. By means of a powerful galvanic battery, brought into a vigorous state of action, this extraordinary effect was produced upon the potassa. Other methods are now adopted for procuring potassium, the principle of which is, to abstract the oxygen united to it in the potassa by means of some

substance, as iron or charcoal, which has an use for it. In this way the potassium sold is no longer compared. The process by which it is procured is rather a difficult and expensive one, so that potassium bears a very high price; a pound weight costs from £100 to £120 sterling.

361. The same means which were used to determine the composition of the alkalies, potassa and soda, and being applied with the view of discovering the nature of the earths, the same results were obtained. Each earth was found to consist of a peculiar metal in union with oxygen. So strong is the attraction, however, which these metals have for oxygen, that it is extremely difficult to separate them, and almost impossible to prevent the metal abstracting oxygen from the air and returning to the state of earth. Hence these metals are not common; they have been seen only by a few chemists, and even these have only a glimpse of some of them,—merely seen them for a moment,—and, shortly after, they have disappeared, combining with some matter around them, thus losing their metallic form. When heated in contact with oxygen, all these metals speedily lose their metallic condition, lustre, &c., and become earths, thus affording the synthetic proof of the composition of the earths. Thus it is now well established that caustic potash, caustic soda, lime, magnesia, the earth of clays (alumina), and several other kinds of earthy matter which make up by far the greater portion of all mineral bodies, consist of a metal in union with oxygen.

362. Potassium possesses very remarkable properties. It is very light, its specific gravity being only 0.865, so that it actually floats upon water.

soft, malleable, and has a brilliant metallic lustre like silver or mercury. It passes into vapour at a low red heat (about 800° F.) and melts at so low a temperature as about 150°. It has a very strong affinity for oxygen, more powerful than between almost any other two elements. Exposed to the air it speedily attracts oxygen, and becomes an earthy powder (potassa). When it comes into contact with water, it abstracts the oxygen from this compound, and a singular action takes place, which terminates in its being turned into potassa, which remains in union with the water, for which this alkali (potassa) has a very powerful affinity. Whenever it touches the water, it takes fire, burns with a reddish or violet flame, and moves rapidly over the surface of the water, slight explosions taking place, great heat being evolved, and a quantity of gas formed. Sodium (the metallic base of soda) is very similar to potassa in its appearance and properties, and presents similar phenomena with air and water.

363. The peculiar action of these metals with air and water has been made, by Sir Humphry Davy, the basis of a theory of volcanic action. These elements are supposed to exist in the interior of the earth in the metallic state. Through fissures in the rocks, air and water (chiefly sea-water) are conjectured to get access to these metallic bases. The metals (the metallic bases of the earths being also considered as engaged in a somewhat similar manner) become oxidized, great heat is produced, and gases evolved, which, being at a high temperature, have great elastic force, and hence the violence of the actions. Part of the hydrogen and nitrogen eliminated from water and air will unite and form

ammonia, which, uniting with chlorine, evolved from rock-salt or salt in the sea-water, will produce sal-ammoniac, an abundant volcanic product. Part of the hydrogen will unite with sulphur and form sulphuretted hydrogen gas; and part of the oxygen from the air, uniting with other portions of sulphur, will give rise to the sulphureous vapours (sulphurous acid gas) which emanate from volcanoes. Part of the nitrogen will be given off uncombined, and hence the source of nitrogen in the gases given off from volcanoes and in hot springs. At the same time, large quantities of steam will be formed and evolved. The elimination of hydrogen furnishes a leading element for the formation of several products of volcanic action, as sal-ammoniac, sulphuretted hydrogen.

364. This view of the cause (or a co-operating cause) of volcanic action is supposed to be strengthened by the circumstances that volcanoes are generally situated near water, in islands, or along the sea-coast, and that potassa and soda abound in the various products of volcanic action. It is considered probable that some more extended cause of volcanic action, such as mechanical disturbance of an internal fluid mass at a high temperature, and therefore ready to burst out where it may find a crevice or diminished resistance, must be looked to for an explanation of many volcanic phenomena; particularly in former geological periods. The hypothesis of Davy may be correct, but most of the effects of volcanic action may be explained without it, and it can hardly be admitted as the sole cause of these convulsions.

Volcanic action is not confined to the interior of the earth, but is also observed in the atmosphere, and even in the moon.

364. GENERAL ACCOUNT OF SILICA, ALUMINA, AND LIME, THE LEADING EARTHS; BARYTA, STRONTIA, MAGNESIA, THORINA, GLUCINA, YTTRIA, ZIRCONIA, ALSO EARTHS, BUT RARE; AND POTASSA, SODA, AND OXIDE OF IRON.

365. The crust of the globe is chiefly made up of three different kinds of earth, SILICA, ALUMINA, and LIME. The proportion which the others bear to these is small. These earthy matters are insoluble, or very sparingly soluble. They are infusible separately, but combined with each other are more easily melted by heat.

1. *Silica, or Flinty Earth.*

366. Silica, or the earth which exists in quartz, gravel, flint, and sand, is, when pure, of a white colour, but in nature it is generally found more or less coloured from the presence of some other substances, such, for instance, as oxide of iron. Silica derives its name from being the chief ingredient in flint, which in Latin is called *silex*. Flint contains, in 100 parts, 98 of silica, the rest being alumina, lime, oxide of iron, and water. Silica enters into the composition of about 2-3ds of all the earthy minerals which have been analyzed, and many minerals consist of it alone. It is a chief ingredient in most rocks and mountains, and is altogether the most abundant earthy substance known. Silica enters largely into the composition of quartz, felspar, mica, hornblende, chlorite, sandstone, aluminous schist or shale, and many other minerals;—granite, which every one knows to be so abundant,

is composed of quartz, felspar, and mica; *grauwacke* is somewhat similar in composition; and basalt or whinstone, also plentiful, consists chiefly of felspar and hornblende. All sorts of slates, clays, and soils, contain a considerable quantity of this universally diffused earth. Silica is obtained in fine powder by exposing colourless rock-crystal to a red heat for some time, and then pounding, this being easy after the mineral has been heated.

367. Silica is particularly distinguished by its *hardness*, as is well seen in flint, sand, &c.; and it communicates this property to all rocks or minerals which contain much of it. They scratch glass, and are not scratched by a knife. From its extreme hardness, stones containing silica are those which are used for striking a light with steel. Owing to its hardness, silica, even when prepared pure and in the powdery form by chemical operations, creates a rough, hard, and gritty feeling when pressed between the fingers, and, when mixed with water, does not form a soft cohesive pasty mass like clay.

368. ROCK-CRYSTAL OR QUARTZ and FLINT are very pure varieties of silica, and the amethyst, opal, and many other precious stones, consist chiefly of this earth. CALCEDONY, AGATE, CARNELIAN, CAT'S EYE, and JASPER consist chiefly of silica. The AMETHYST (violet quartz), which is of a violet or purplish-violet colour, is coloured by a very minute quantity of oxides of iron and manganese. The precious OPAL, which is of a white or bluish-white colour, and presents such a singular play of colours (green, blue, yellow, and red), contains, in 100 parts, 90 of silica and 10 of water. The sand of the seashores, and, indeed, almost all sand, consists entirely of silica, and

this earth forms the chief ingredient of flint ; which is indeed a natural variety of tolerably pure silica. Jasper contains a large proportion of silica, along with a little oxide of iron, to which it owes its colour.

369. Silica is not corroded by the acids (except the hydrofluoric), and is little altered by the action of heat ; it is quite incombustible, already containing oxygen, the matter which, by its combining chemically with other bodies, constitutes combustion. It is very infusible, yielding only to the action of the oxy-hydrogen blowpipe. United with alkalies or other earths, it is more easily fused by heat. United with alkalies (soda or potassa) silica is soluble, but in its ordinary state it is quite insoluble in water. When this liquid, however, is presented to it in the *nascent* state (the silica in the act of separating from its chemical union with some other body), a considerable quantity is dissolved.

370. From its insolubility, and from not being affected by the acids, it is used largely for the manufacture of glass and every kind of porcelain and pottery ware. The Lynn sand, used in the manufacture of the better kinds of glass, is a tolerably pure variety of silica. Asbestos contains much silica, and from being unaltered by the action of heat, this substance was manufactured by the ancients into a kind of cloth, which was used for wrapping up the bodies of the dead when about to be burned on the funeral pile.

371. From its hardness and great insolubility, silica is the most durable of the earths. It seems to be the basis or support of the other ingredients of the crust of the earth ; and when rocks and even mountains are, in the course of ages, decomposed,

broken up, and reduced to fragments or to earth by the effects of wind, rain, frost, and the air, siliceous earth is the matter which remains, forming beds of stones and sand, and being the last to be reduced to powder, its hardness preventing its being pulverized by the friction produced by the action of water rubbing its particles against each other, so that it is not so easily lifted up and carried away in suspension in rivers and streams. Hence sand and siliceous pebbles form the chief part of the beds of rivers and the sea. Many of the other matters of rocks act the part of a cement, binding the particles of silica to each other. Thus, silica may be said to be the *bones of the earth*, giving hardness and firmness, and rendering rocks durable, so that they can better resist the forces which tend to destroy them. Like the bones of animals, silica is the last to crumble down. More than one-half of the crust of the globe may be considered as consisting of this earth.

372. Silica consists of equal weights of oxygen, and another matter called *silicium* or *silicon*. When the composition of silica was first ascertained, the substance associated with the oxygen was regarded as of a metallic nature, and accordingly the termination *um* was given to it. More lately, chemists have been inclined to question its metallic nature, and to class it along with carbon and boron. Its name has now therefore been altered to the termination *on*, although it is not yet considered quite a settled point that it is not of a metallic nature. There is no doubt, however, that silica consists of oxygen and a substance which, in some points at least, bears a considerable resemblance to the metals.

2. *Alumina, or Earth of Clays.*

373. Next to silica, alumina is the most abundant of the earths. It is a principal ingredient in almost all rocks and soils that are not essentially sandy in their nature. It is a leading ingredient in the composition of all clays, pipe-clay, for example; and it is this substance which gives to clays that softness and smooth feel, and that plasticity and adhesiveness, by which we are enabled to mould them into bricks, tiles, china, and the various kinds of porcelain and pottery ware,—mixing easily with water and forming a cohesive pasty mass. It is from an abundance of this peculiar earth that clay soils derive their character, and, mixed with silica and lime, it is found almost every where over the surface of the earth. It is not so abundant or so frequently met with in the pure state as silica.

374. Alumina is so called from being the leading ingredient in alum, from which it is procured when required pure for chemical purposes. It is also called *argillaceous earth*, or argil, from a Latin word signifying clay. When pure, alumina is of a fine white colour. As it exists in nature, it is always coloured from the presence of other matters, oxide of iron being in general the colouring matter.

375. To procure alumina from alum, this crystalline substance is dissolved in water, and carbonate of potash is added, when the alumina is precipitated in the form of a soft, white, bulky powder, which is purified by other processes. This earth may also be easily procured by heating strongly the sulphate of alumina and ammonia. Pure alumina is a very insipid substance, having neither taste nor

smell—is not dissolved by water, and requires a very intense heat to cause it to melt. It has a great affinity for water, with which it forms a hydrate.

376. Clay, besides alumina, contains silica, carbonate of lime, and oxide of iron. Mr Wedgwood found the porcelain clay of Cornwall to be composed of sixty parts of alumina and twenty of silica; clay in general, however, contains a much larger proportion of silica; the alumina in most clays is in the proportion of 1-3d or 1-4th. When present in about that quantity it communicates the argillaceous character.

377. It is curious that many of the gems most esteemed for their hardness and brilliancy are composed of alumina. The sapphire, one of the most rare, and deemed, of all the precious stones, next in value to the diamond, consists almost entirely of the earth alumina, which in another form, that of clay or earth, is so common and so little valued. One hundred parts of the SAPPHIRE contain 98·5 of alumina, 0·5 of lime, 1·0 of the oxide of iron. There are many varieties of sapphire, differing chiefly in the colour, which is generally white, blue, yellow or green. The yellow kind is called the oriental topaz; the blue, the oriental sapphire; the green, the oriental emerald; the violet-blue, the oriental amethyst. The ORIENTAL RUBY contains in a hundred parts, 90 of alumina, 7·0 of silica, and 1·2 of the oxide of iron: to the latter ingredient it owes its rich red colour. This ruby is, next to the sapphire, the most valued of the precious stones. The ORIENTAL TURQUOISE, of a greenish-blue colour, contains in 100 parts, 73 of alumina, 4·5 of the oxide of copper, to which the colour is chiefly to be attributed.

buted, 4.0 of the oxide of iron, and 18.0 of water. The white Brazilian TOPAZ contains, in 100 parts, 50 of alumina, 20 of silica, and 19 of hydrofluoric acid ; those of a yellow colour contain a little oxide of iron. The garnet and many other precious stones contain this earthy matter. The precious garnet, or almandine, consists of 35.75 parts of silica, 27.25 of alumina, 36 of oxide of iron, and 0.25 of the oxide of manganese. The common garnets contain also a quantity of lime.

378. Felspar, perhaps the most generally diffused mineral substance, next to quartz and oxide of iron, contains, in 100 parts, about 17 of alumina, the rest being chiefly silica and potash. Felspar is an ingredient in granite, grauwacke, and basalt, three very abundant rocks. Mica, which also exists so abundantly in rocks, as granite, gneiss, mica slate, contains, in 100 parts, about 31 of alumina and 46 of silica ; the rest being chiefly potash and oxide of iron. All slaty minerals contain a considerable quantity of alumina, about 25 parts in 100. Hornblende, which forms part of basalt or whinstone, and other rocks, contains, in 100 parts, about 12 of alumina.

379. Alumina consists of a peculiar substance, now called aluminium, in union with oxygen. This was proved by Sir Humphry Davy, who found that potassium, when brought into contact with alumina at a very high temperature, acquired oxygen from the alumina, and became converted into potash. The substance united with the oxygen in the alumina was proved by Wohler, as inferred by Sir Humphry Davy, to be a metal. This metal has been obtained in small quantities by a few chemists.

Like potassium, it is procured with difficulty, being united to the oxygen by a very strong affinity. When heated strongly in contact with the atmosphere, it unites with oxygen, and becomes alumina; when burned in oxygen, it becomes converted into a hard matter resembling corundum; this mineral consists of alumina in union with a little silica and oxide of iron.

3. *Lime.*

380. The next earthy constituent of rocks and soils is—lime, or perhaps it would be more correct to say, carbonate of lime. Pure lime is not found native, being procured only by artificial processes: in nature, lime is always found in chemical union with other matters, chiefly carbonic acid. In this form, lime is very abundant. Chalk, marble, limestone, coral, marine shells, consist chiefly of carbonic acid in union with lime.

381. When carbonate of lime (as limestone) is exposed to a considerable heat, the carbonic acid is expelled from the limestone; what remains is *lime* (or, as it is often called, quick lime, caustic lime, burnt lime, roche lime). This is the substance used for the preparation of mortar, for this purpose being mixed with water and sand.

382. Lime is similar in its composition to alumina; it consists of a metal, CALCIUM, in union with oxygen: the metal is procured with difficulty, and its properties are not well known.

383. Lime, in union with carbonic acid, is a very abundant mineral, forming, as has been calculated, about 1-8th of the crust of the earth. In union with sulphuric acid (oil of vitriol), forming sulphate

of lime, lime is frequently met with; gypsum is the common name of the sulphate of lime found in nature. Lime is also found in union with fluoric acid, as in Derbyshire spar, and occasionally in union with phosphoric acid (a compound of phosphorus and oxygen); but it is in the state of carbonate of lime that this earth is so abundant. There are mountains, and many beds of rocks in the interior of the earth, composed of limestone.

4. *Magnesia, Baryta, Strontia, &c.*

384. MAGNESIA is not nearly so abundant as the other materials of rocks. When procured by itself, it is a very light earth, of a fine white colour, extremely insipid (in which it differs from lime, baryta, and strontia);—like lime and alumina, it consists of a metal, MAGNESIUM, in union with oxygen. Asbestos contains a considerable quantity of magnesia, and this earth is a principal ingredient in mountain leather, mountain wood, and mountain cork, three singular minerals, possessing much of the softness, flexibility, and lightness of leather, wood, and cork, being so light as to float on water. Hornblende contains magnesia. Most minerals which are characterized by their softness, lightness, or soapy feel, contain a considerable proportion of magnesia. Magnesia, much used in medicine, is a well known substance. It is very insoluble; its compound with carbonic acid (carbonate of magnesia) is also insoluble; but with sulphuric acid, it forms a very soluble substance—Epsom salt or sulphate of magnesia. Magnesia is abundant in union with carbonic acid and carbonate of lime in magnesian limestone.

385. The earthy matters called BARYTA and

STRONTIA are exactly similar to lime in their composition and leading properties. They are not abundant. The compounds of baryta are distinguished by being heavy and poisonous: the most abundant barytic mineral is the sulphate of baryta, well known by the name of *heavy spar*. This, and carbonate of baryta and carbonate of strontia, are the minerals in which these earths are found. Lime, baryta, and strontia are distinguished from the other earths by being found in nature in union with acids (lime is found in several minerals without any acid), by being very caustic, and having a sharp taste, by having a great affinity for water and for all the acids, by being a little soluble in water, and by forming, with carbonic acid, compounds which are insoluble in water, and, with sulphuric acid, compounds which are very sparingly soluble in water. Silica is never found in union with acids—alumina rarely.

386. As to the other matters—**GLUCINA**, **YTTRIA**, **ZIRCONIA**, **THORINA**—little need be said of them here; they are found in very small quantities, and are exceedingly rare. They resemble the earthy matters in their properties and composition. It is sufficient here to know that there are such bodies, differing in some points from the other earthy bodies which are so abundant. The **EMERALD** and **BERYL** contain glucina united with silica, alumina, and lime. The beryl owes its colour to a little oxide of iron; the emerald, to oxide of chrome. Zirconia forms about 70 parts in 100 of the **HYACINTH**, the rest being silica and oxide of iron. Yttria constitutes about half of a rare mineral called **GADOLINITE**. Thorina forms about 58 parts in 100 of a mineral called **THORITE**.

387. Besides these, there are a few other substances, which require to be noticed in a general view of the chemical composition of the earth, *oxide of iron, oxide of manganese, potash, and soda.* These do not exist in large quantities in the earth, but they are very widely diffused, a great number of the most abundant minerals containing a little of these matters.

388. There are two different OXIDES OF IRON, a black and a reddish-brown; the latter differing from the former solely in containing a larger quantity of oxygen. *The oxide containing the smaller proportion of oxygen has always a disposition to unite with more oxygen and become converted into the red oxide.* Oxide of iron is found almost every where in rocks and soils, and in a great number of cases it is oxide of iron which gives colour to particular minerals.

389. OXIDE OF MANGANESE, as its name indicates, consists of some matter in union with oxygen. This matter is a metal, so that oxide of manganese is analogous in its composition to the other earthy matters of the globe. Though it exists in minerals in very small quantities, it is found in a great number, being a very widely-diffused mineral substance; and often communicates a peculiar colour, dull red, or brownish red.

390. POTASH is the matter which, when in union with carbonic acid, forms the common potashes or pearlash of the shops. These matters are—carbonate of potash. The terms potash and potassa are synonymous. Potash consists of potassium in union with oxygen, and is characterized by being exceedingly caustic, having a great affinity for water, and

also for carbonic acid, in virtue of which it is enabled to abstract water and carbonic acid from the air; and hence minerals which contain it are decomposed on exposure to air.

391. Soda bears the same relation to carbonate of soda (carbonate of soda) as potash does to potash, and consists of a peculiar metal much resembling potassium, and oxygen. This metal is called sodium. In its general properties and chemical relations it resembles potash.

392. Potassa and soda are very abundant, being in considerable quantities in the minerals which compose volcanic rocks, as obsidian, pitchstone, &c. See potassium and sodium, in the tables in 41 and 42.

393. Putting out of consideration at present the native metals, metallic ores (those minerals which the common metals are procured from), salts, and combustible minerals, all the mountains and rocks, and soils of every kind, stones, gems, &c. are composed of these few ingredients. And, if we consider that carbonate of lime forms 1-6ths of the crust of the globe, and silica and alumina 6-8ths, we may safely say that silica, alumina, and carbonate of lime are the principal ingredients in the composition of the earth, although there is a variety of other matters scattered up and down. It has been calculated that SILICA, ALUMINA, MAGNESIA, and OXIDE OF IRON form 19-20ths of the crust of the globe.

394. All the earths, when obtained pure by chemical processes, are of a white colour. But a few minerals present this colour;—black, gray, brown, &c., are the most common colours of

and rocks. Rocks owe this colour chiefly to admixtures of the oxide of iron, and in some cases to the oxide of manganese ; soils owe their peculiar colours partly to these, and partly to the presence of charcoal.

IV. GENERAL VIEW OF THE ROCKY MASSES WHICH EXIST IN THE CRUST OF THE EARTH.

395. In the following account or list of the leading rocks which have been found in the earth, it is not necessary for the understanding of it that the reader should have seen and be acquainted with the appearance of the rocks and mineral bodies mentioned. This would imply a knowledge of *mineralogy* and *geology*, the former of which makes us acquainted with the appearance, form, and composition of the various minerals which compose rocks and earth, while the latter considers these as aggregated in rocks or strata, with reference to their general structure, relative situation, mode of formation, and changes which they undergo. The object of this and the following section is to convey to the chemical student some idea of the *chemical composition* of the earth. This may be obtained, sufficient for the general reader, without mineralogy or geology. For example, he will see *granite* mentioned. Perhaps he never saw granite or never even heard of it before ; but he sees that it consists of three minerals, *quartz*, *felspar* and *mica*. These may be equally new to him ; but in the succeeding paragraphs he will see the chemical composition of these minerals, and learn that they are composed of silica, alumina, &c., *substances the nature of which he has become acquainted with in the preceding section ;*

he will thus know of what materials the earth around him is composed—all that chemistry has to teach of the nature of the earth. If further information be desired, this is supplied by the kindred sciences of mineralogy and geology.

396. The rocky masses are very conveniently divided into two classes, the **UNSTRATIFIED ROCKS**, and the **STRATIFIED ROCKS**.

397. The **UNSTRATIFIED rocks** are called also **VOLCANIC**, **IGNEOUS**, **PLUTONIC**, these terms signifying that fire has been concerned in their formation. They are those which show distinct evidences of volcanic action, both in the situation and form of the mass, and in the internal structure of the rock.

398. They are not disposed in regular layers parallel to each other like the stratified rocks, but form irregularly shaped, often rounded masses, frequently standing out alone, almost entirely isolated from the neighbouring masses of rock, projecting through and across the stratified rocks or in between them.

399. When their internal structure is examined, they are generally found to consist of dissimilar crystals aggregated together, the whole presenting, even when the crystals are so minute as to be hardly distinctly perceptible, a highly crystalline texture.

400. There are two principal kinds of unstratified rocks, **GRANITE** and **VOLCANIC ROCKS**, including under the latter name lava, greenstone, serpentine, basalt, and all volcanic rocks except granite.

401. The unstratified rocks are considered to have been thrown into their present position and form by the volcanic energy, being ejected in the liquid state, assuming the rounded, peaked, or pre-

cupitous and columnar state, according to the direction of the force and condition of the medium into which they were projected. They are supposed to have become solid by cooling. Their particles, when solidifying, collect together according to certain chemical affinities and form distinct mineral compounds, and assume the crystalline form, as is usual when a liquid passes to the solid state from being lowered in temperature.

402. The STRATIFIED rocks are also called NEPTUNIAN or SEDIMENTARY. They include those which are found regularly arranged in strata or layers, lying parallel to each other. When their consistence is examined, they are found to present the appearance of a number of similar earthy particles of greater or less size adhering to each other (sandstone, clay, limestone), being then quite homogeneous in their texture; or they exhibit what are evidently broken fragments of other rocks scattered through their substance (millstone grit, conglomerate, breccia).

403. The following general list and view of the arrangement of the stratified rocks is extracted from the article GEOLOGY in the *Encyclopædia Metropolitana*.

“ The following Table exhibits a complete view of the whole series of British strata, grouped according to their relative antiquity into three leading divisions, the Primary, Secondary, and Tertiary strata; it being understood that such divisions are chiefly adopted for convenience, as expressing with considerable accuracy certain general analogies of origin, composition, and organic contents, which prevail amongst the members of each division, but yet are

not to be considered as exclusively belonging to them.

“Two of these divisions are again subdivided upon exactly the same principles into systems of strata, which are marked by certain recurrent rocks, striking analogies of composition, organic reliquæ of similar types, and positions derived from convulsions of the same epoch.

“The systems are again usefully divided into formations; these into their several component rocks; whose ultimate analysis gives the strata, beds, and laminæ of composition. The superficial accumulations of gravel, sand, peat, &c., which are classed under the head of diluvial and alluvial deposits, are not included in this list of strata.

“For the sake of the student to whom the mode of considering the sequence of rocks may not be familiar, the strata are here placed in the same order as they would be found on proceeding from the surface downward.

“TERTIARY SERIES OF STRATA,

Partly lacustrine, but principally marine, sandy, and argillaceous, and with some calcareous deposits, abounding in shells, and other organic exuvix, closely analogous to existing species.

Formations.	Usual thickness of Formation. Feet.	Stratified Groups.
1. Upper marine formation }	50.....	{ Sandy crag with shells. Zoophytic limestone. Upper freshwater lime- stone and marls.
2. Marinolacustrine }	100.....	{ Intermediate marine bed. Lower freshwater lime- stone and marls.

Formations.	Usual thickness of Formation. Feet.	Stratified Groups.
3. Lower marine } formation }	1000 or more }	London clay group Bagshot sand. London clay.
		Plastic clay group Plastic clay with co- loured sands and lignites. Shelly blue clays and sands. Pebbly green sands.

“ SECONDARY SERIES OF STRATA,

Principally of marine origin, with rare and local estuary deposits; consisting of repeated alternations of limestone, flint, sandstone, sand, clay, iron ores, coals, salt, &c., with organic remains generally very distinct from existing forms of animals and plants.

Cretaceous System.

Formation.	Thickness. Feet.	Stratified Groups.
4. Chalk.....	600	Upper soft chalk with flints.
		Middle harder chalk.
		Lower marly chalk.
		Red chalk.
5. Green sand....	500	Green and gray sands.
		Gault clay.
		Iron sand or lower green sand.

Oolitic System.

6. Wealden .....	.....	Weald clay and Sussex marble.
		Hastings sands and limestones.
		Purbeck limestones and clays.

Formation.	Thickness. Feet.	Stratified Groups.
7. Upper oolite	400	{ Portland oolite and other limestones. Kimmeridge clay. Upper calcareous grit. Coralline oolite. Lower calcareous grit.
8. Middle oolite	{ Coralline oolite group Oxford clay group	{ Oxford clay. Kelloway calcareous grit rock. Clay.
9. Lower oolite	.....	{ Cornbrash limestone. Forest marble and sands. Great oolite. Fullers' earth, rock, and clays. Inferior oolite. Ferruginous sand.
10. Lias	.....	{ Upper lias clay, or shale. Marlston beds, sandy and calcareous. Lower lias clay, or shale. Lias limestone. Dark marls.

Saliferous System.

11. Variegated sandstone (<i>Pæcilite</i> , <i>Conybeare</i>)	}	.....	{ Variegated marls, gypsum, and salt. Red and white sandstone. Red sandstone conglome- rate.
12. Magnesian limestone	}	.....	{ Red and white marls. Laminated limestone. Gypseous red and white marls. Magnesian limestone; Marl slate. Rothetodteliegende.

Carboniferous System.

Formation.	Thickness. Feet.	Stratified Groups.
13. Coal.....		{ Alternating. Sandstones. Shales. Coals. Ironstones, &c., resting on Millstone grit.
14. Mountain } limestone }		{ Alternating. Limestones. Shales. Gritstones. Seams of coal.
15. Old red } sandstone }		{ Conglomerates. Flagstones. Red and white marls.

“ PRIMARY STRATA,

Containing organic remains, mostly of extinct tribes, and only in the upper part of the series.

Slate system, including many great divisions which eventually may be classed in formations, according to their organic remains and bands of limestone. It is a *usual*, but vague classification, to distinguish this system into upper or fossiliferous, and lower or non-fossiliferous slates and limestones.

Gneiss and mica schist system, including mica schist, chlorite schist, hornblende schist, quartz rock, primary limestone, gneiss, &c.

Granitic rocks, which are not stratified, usually form the basis of the strata, and are frequently but not by any means universally followed by the gneiss and mica slate system.”

404. It is generally considered as quite established that these, the stratified rocks, have been deposited from water; their particles having been either mechanically suspended in the water, or precipitated from solution in the water by some chemical

action, after which they are in the state of mechanical suspension. Having thus fallen to the lower part or bed of the liquid in which they were suspended, they formed a horizontal layer at the bottom; a succession of these deposits gives a series of parallel strata; the particles cohering together form a series of hard rocks; elevated above the waters, they form the land; and broken and disturbed by volcanic eruptions, which cross them, rush in between the beds, and even break them and separate a broken mass from the others, they present the appearance and structure in which we now find these once horizontal beds.

405. Those rocks or strata which are to be regarded as chemical precipitates are carbonate of lime, magnesian limestone (carbonate of lime and magnesia), gypsum (sulphate of lime), rock-salt (chloride of sodium), ironstone (carbonate of iron), and coal. The latter can hardly be considered a chemical *precipitate*—but its production seems dependent chiefly on chemical changes in the matter from which it is formed.

406. The others which are considered as having been deposited from mechanical suspension in a fluid, are believed to have been derived from the disintegration of the primary rocks, pieces being successively detached from these rocks, broken into small fragments, and pulverized by agencies which we shall examine immediately, and carried by means of water into the sea or large lakes, in which, when the water became still, they subsided and formed a stratum at the bottom. In this way the sandstones, conglomerates, and clays, &c. seem to have been formed.

407. It is considered that the proportion of mechanical sediment to chemical precipitate in the entire mass of the stratified rocks is as 88 or 90 to 1.

V. DIVISION OF THE ROCKS INTO SIMPLE MINERALS,
AND CHEMICAL COMPOSITION OF THESE.

408. All these rocks are compounded of certain simple minerals in powder, grains, or larger fragments. To examine the composition therefore of the rocks, we shall inquire what are the simple minerals of which each consists, and then state in detail the chemical composition of these simple minerals.

409. The following are the leading rocks with the simple minerals which enter into their composition, as given by Sir H. Davy, in his *Agricultural Chemistry*.

“Rocks are generally divided by geologists into two grand divisions, distinguished by the names of ‘primary and secondary.’

“The primary rocks are composed of pure crystalline matter, and contain no fragments of other rocks.

“The secondary rocks, or strata, consist only partly of crystalline matter; contain fragments of other rocks or strata; often abound in the remains of vegetables and marine animals; and sometimes contain the remains of land animals.

“The primary rocks are generally arranged in large masses, or in layers, vertical, or more or less inclined to the horizon.

“The secondary rocks are usually disposed in strata or layers, parallel or nearly parallel to the horizon.

“ The number of primary rocks which are commonly observed in nature are eight.

“ First, *granite*, which, as has been mentioned, is composed of quartz, felspar, and mica ; when these bodies are arranged in regular layers in the rock, it is called *gneiss*.

“ Second, *micaceous schistus*, which is composed of quartz and mica arranged in layers, which are usually curvilinear.

“ Third, *sienite*, which consists of the substance called hornblende, and felspar.

“ Fourth, *serpentine*, which is constituted by felspar and a body named resplendent hornblende ; and their separate crystals are often so small as to give the stone a uniform appearance : this rock abounds in veins of a substance called *steatite* or *soap-rock*.

“ Fifth, *porphyry*, which consists of crystals of felspar, embedded in the same material, but usually of a different colour.

“ Sixth, *granular marble*, which consists entirely of crystals of carbonate of lime ; and which, when its colour is white and texture fine, is the substance used by statuaries.

“ Seventh, *chlorite schist*, which consists of chlorite, a green or gray substance somewhat analogous to mica and felspar.

“ Eighth, *quartzose rock*, which is composed of quartz in a granular form, sometimes united to small quantities of the crystalline elements, which have been mentioned as belonging to the other rocks.

“ The secondary rocks are more numerous than the primary ; but twelve varieties include all that are usually found in these islands.

“ First, *grauwacke*, which consists of fragments of quartz, or chlorite schist, embedded in a cement, principally composed of felspar.

“ Second, *siliceous sandstone*, which is composed of fine quartz or sand, united by a siliceous cement.

“ Third, *limestone*, consisting of carbonate of lime, more compact in its texture than in the granular marble; and often abounding in marine exuviae.

Fourth, *aluminous schist* or *shale*, consisting of the decomposed materials of different rocks cemented by a small quantity of ferruginous or siliceous matter; and often containing the impressions of vegetables.

“ Fifth, *calcareous sandstone*, which is calcareous sand, cemented by calcareous matter.

“ Sixth, *ironstone*, formed of nearly the same materials as aluminous schist, or shale; but containing a much larger quantity of oxide of iron.

“ Seventh, *basalt* or *whinstone*, which consists of felspar and hornblende, with materials derived from the decomposition of the primary rocks; the crystals are generally so small as to give the rock a homogeneous appearance; and it is often disposed in very regular columns, having usually five or six sides.

“ Eighth, *bituminous* or *common coal*.

“ Ninth, *gypsum*, the substance so well known by that name, which consists of sulphate of lime; and often contains sand.

“ Tenth, *rock-salt*.

“ Eleventh, *chalk*, which usually abounds in remains of marine animals, and contains horizontal layers of flints.

“ Twelfth, *plum-pudding stone*, consisting of pebbles cemented by a ferruginous or siliceous cement.

“ The highest mountains in these islands, and indeed in the whole of the old continent, are constituted by granite ; and this rock has likewise been found at the greatest depths to which the industry of man has as yet been able to penetrate ; micaceous schist is often found immediately upon granite ; serpentine or marble upon micaceous schist : but the order in which the primary rocks are grouped together is various. Marble and serpentine are usually found uppermost ; but granite, though it seems to form the foundation of the rocky strata of the globe, is yet sometimes discovered above micaceous schist.”

410. The stratified rocks are chiefly of three kinds with respect to composition :—

Siliceous,
Silico-argillaceous,
Calcareous.

Fragments of quartz characterize the siliceous rocks. Felspar, mica, chlorite, are the minerals which give the silico-argillaceous rocks their peculiar character. The calcareous rocks consist chiefly of carbonate of lime.

Quartz rock, conglomerates, and sandstone, are the chief varieties of siliceous rock.

Mica-schist, chlorite-schist, shale, are examples of silico-argillaceous rock.

Marble, chalk, marl, limestone, oolite, are calcareous, consisting chiefly of carbonate of lime.

411. In the above general view of the rocky

masses which compose the crust of the earth, it will be observed that there are only about ten *different* kinds of minerals mentioned, the same mineral sometimes entering into the composition of several kinds of rocks. The ten different minerals, which, either separately or compounded in various ways, make up almost the whole of the rocky masses, are, quartz, felspar, mica, hornblende, steatite, carbonate of lime, chlorite, coal, gypsum, rock-salt. The following tables of the chemical composition of these minerals will convey a tolerably correct general notion of the *chemical composition of the rocky masses which compose the greater part of the crust of the earth, and of the proportions of their different ingredients.*

I. QUARTZ.

Quartz consists almost entirely of silica; frequently mixed with a little alumina and oxide of iron, or combined with a small proportion of water.

II. FELSPAR

Contains, in 100* parts,

Silica,	.	.	.	.	62·83
Alumina,	.	.	.	.	17·02
Potash,	.	.	.	.	13·
Lime,	.	.	.	.	3·
Oxide of iron,	.	.	.	.	1·

* It will be observed that the proportions of the different ingredients do not always make up the 100 parts; the remainder, seldom above 2 or 3 parts, is to be set down as *loss*, almost unavoidable during the analysis of minerals containing so many different ingredients.

COMPOSITION OF THE

III. MICA

Contains, in 100 parts,

Silica,	46.10
Alumina,	31.16
Potash,	8.39
Oxide of iron,	8.65
Oxide of manganese,	1.40
Water,	0.87
Fluoric acid,	1.12

IV. HORNBLLENDE

(Common Hornblende)

Contains, in 100 parts,

Silica,	42.
Alumina,	12.
Oxide of iron,	30.
Lime,	11.
Magnesia,	2.25
Water,	0.75
Ferruginous* manganese,	0.25
Potash,	

V. STEATITE

Contains, in 100 parts,

Silica,	64.
Magnesia,	22.
Water,	5.
Oxide of iron,	3.

VI. CARBONATE OF LIME

(Common Limestone)

Contains pure carbonate of lime, consisting, in 100 parts, of

Lime,	56.
Carbonic acid,	44.

* Mixed with iron.

and small proportions of silica, alumina, magnesia, and oxide of iron; the quantities of these varying in different specimens.

VII. CHLORITE

(*Earthy Chlorite*)

Contains, in 100 parts,

Oxide of iron,	.	.	.	43.
Silica,	.	.	.	26.
Alumina,	.	.	.	18.5
Magnesia,	.	.	.	8.
Chloride of sodium (or potassium),	.	.	.	2.

VIII. COAL

(*Cherry or Soft Coal*)

Contains, in 100 parts,

Charcoal,	.	.	.	74.45
Hydrogen,	.	.	.	12.4
Nitrogen,	.	.	.	10.22
Oxygen,	.	.	.	2.93

IX. GYPSUM

(*Selenite*)

Contains, in 100 parts,

Lime,	.	.	.	32.7
Sulphuric acid,	.	.	.	46.3
Water,	.	.	.	21.

X. ROCK SALT

(*Of Cheshire*)

Contains, in 1000 parts,

Chloride of sodium,	.	.	.	983.25
Sulphate of lime,	.	.	.	6.25

little muriate of magnesia and muriate of lime, and 10 parts of insoluble matter.

412. Having seen that the rocks are composed of a certain class of bodies called **SIMPLE MINERALS**, the preceding tables show us that these simple minerals are composed of—

Silica	Potash	Carbon
Alumina	Soda	Hydrogen
Lime	Carbonic Acid	Nitrogen
Magnesia	Sulphuric Acid	Oxygen
Oxide of Iron	Water	Chlorine

413. These, excepting the five last, are compounds, the composition of which has been already explained. We shall conclude this account of the chemical composition of the strata and masses of rocks with a classified list of the elements of which they are all composed. See paragraph 66 for a list of the more abundant elements. The others occur in very small quantities, and in very few situations.

414. A correct classification of the elements is difficult. The most convenient is into *non-metallic* and *metallic*. The subdivision of the non-metallic elements which appears most appropriate, is that of *Berzelius*, into *gazolytes* (bodies permanently gaseous), *metalloids* (bodies which resemble the metals in many chemical relations), and *halogens* (bodies which produce salts when in union with the metals). The metallic elements are more easily classified. The following table, then, gives a view of the elements, arranged according to their leading chemical relations, as nearly as that can be done at present.

I. NON-METALLIC.		
Gasolytes.	Halogens.	Metalloids.
Oxygen	Chlorine	Carbon
Hydrogen	Iodine	Boron
Nitrogen	Bromine	Sulphur
	Fluorine	Selenium
		Phosphorus

II. METALLIC.

1. Bases of the alkalis and earths.

Bases of the Alkalies.	Bases of the Alkaline Earths.	Bases of the Earths.
Potassium	Calcium	Silicium
Sodium	Barium	Aluminium
Lithium	Strontium	Thorium
	Magnesium	Glucinium
		Zirconium
		Ittrium

2. Metals whose oxides are not reduced (the oxygen expelled) by the action of heat alone.

a. Metals which decompose water at a red heat.

Manganese	Tin	Cobalt
Zinc	Cadmium	Nickel
Iron		

b. Metals which do not decompose water by heat alone.

Arsenic	Columbium	Titanium
Chromium	Antimony	Tellurium
Vanadium	Uranium	Copper
Molybdenum	Cerium	Lead
Tungsten	Bismuth	

3. Metals whose oxides are reduced by a red heat.

Mercury	Platinum	Osmium
Silver	Palladium	Iridium
Gold	Rhodium	

VI. CHEMICAL RELATIONS WHICH GIVE RISE TO CHANGES AMONG THE VARIOUS INGREDIENTS OF THE EARTH AND SEA.

415. Having now examined the leading properties of the elements and of the earthy compounds they form, the composition of the simple minerals formed by the union of the various earths, and the arrangement of these simple minerals in rocks, we shall be able to understand the action of the chemical affinities which give rise to chemical changes on the earth and in the waters, which performed a leading part in bringing about a number of changes in the geological condition of the crust of the earth, and are still in operation, giving rise to similar effects.

416. A great number of chemical changes in rocks are owing to the relations of iron to other bodies, particularly oxygen. This metal, though not in such large quantities as some other elements, is very widely diffused, there being few rocks in which it is not present, and it is, in a chemical point of view, one of the most active of the elements in the operations of nature.

417. Iron exists in considerable quantity in the interior of the earth in combination with sulphur, forming what is called iron pyrites, or sulphuret of iron. When this is exposed to a high temperature, the sulphur, or part of it, is driven off in vapour. Hence perhaps one source of the sulphur in vapour given off from volcanoes, and which is found condensed into solid sulphur in great quantities in such situations. This substance, united with oxygen, forms sulphurous acid, — with hydrogen, sulphuretted

hydrogen, gases which occur frequently in volcanic districts. The former, when it meets with water, is largely absorbed, and if freely exposed to the air, passes into sulphuric acid. This is found in some lakes near volcanoes. The hydrogen for the formation of the latter may be supposed to be derived from water by the action on this liquid of the metallic bases of the alkalies (363).

418. When iron pyrites is exposed to air and moisture, it absorbs oxygen, and becomes sulphate of iron (green vitriol or copperas), a very soluble salt. The pyrites is quite insoluble. It consists of the two simple bodies, sulphur and iron. These, united to the necessary quantity of oxygen, form the soluble salt called the sulphate of that metal, more properly termed sulphate of the oxide of iron. The sulphuric acid, which is indicated by the term "sulphate," consists of oxygen and sulphur. The salt, in union with the necessary quantity of water, forms the green crystals.

419. It has been conjectured that, in particular circumstances, the reverse operation may take place, and sulphate of iron be turned into sulphuret of iron by losing oxygen, if some substance be present which has an affinity for the latter element. In this way the nodules of sulphuret of iron found in the carboniferous strata may have been formed, the carbon of some organic body separating the oxygen from the sulphate of iron which may have penetrated it in the liquid form.

420. Carbonate of iron is held in solution by water containing carbonic acid, in the same way as carbonate of lime (281). When such water is exposed to the air, oxygen is absorbed, the oxide of iron in

the carbonate combines with this oxygen and some water, and becomes an insoluble hydrate of the peroxide (321) of iron, which is then precipitated as an ochry sediment of a reddish brown tint. A similar deposit takes place from water containing other salts of iron, as the sulphate.

421. If water containing carbonate of iron in solution be heated, the carbonate will be precipitated, as carbonate of lime is, from the expulsion of the carbonic acid (293).

422. Iron in the state of protoxide is an ingredient in many rocks. When a fresh surface of such a rock is exposed to the air, the oxide of iron abstracts oxygen and water, and becomes the *ruddy coloured hydrate of the peroxide of iron*. Thus detached from its chemical union with the other ingredients in the rock, it forms a sort of crust at the surface (exactly like rust on common iron exposed to the air), is soon broken off by the mechanical action of air and water, and a fresh surface is exposed to undergo similar changes.

423. When carbonate of lime is exposed to a strong heat, the carbonic acid is driven off in the gaseous form (quick lime being left). Hence, perhaps, the source of the quantity of carbonic acid found in the streams, hot springs, and lakes in volcanic countries. The volcanic heat in the interior acts in this way on the beds of limestone, and the carbonic acid meeting with water, is absorbed by that liquid, which it endows with certain solvent properties by which it acts on several earthy matters otherwise insoluble. It is not improbable that the slaking of the quick lime thus formed may sometimes aid in the production of volcanic convulsions, water coming

in contact with the lime, uniting rapidly with it, and producing great heat, which evaporates part of the water with great violence, as is seen when water is thrown upon quick lime, the hydrate of lime being then formed.

424. When water containing carbonate of lime in solution is exposed to the air, the carbonic acid which kept the carbonate in solution (281) passes off, and the then insoluble carbonate of lime is precipitated. In this way beds of limestone and great quantities of marble have been deposited in lakes, and such deposits are still going on in many places; very abundantly in some Italian lakes. It is probable that many of the deposits in the tertiary and secondary strata are owing to this action. When water containing carbonate of lime in solution is heated, a similar effect takes place. The additional quantity of carbonic acid is expelled, and the insoluble carbonate is then precipitated.

425. The origin of the great quantity of the carbonate of lime in the crust of the earth (1-8th) has excited some discussion. As it is a secretion of a particular class of marine animals, in their shells, or as coral, it has been conjectured that they may be actually endowed with *the power of forming this from other elements*, by some peculiar vital action transforming them into lime. But it is generally regarded as more probable that, even in these cases, it is formed from lime previously in the water in which these animals grow. According to Dr Marcet, one out of every 500 grains of the water of the Atlantic ocean is muriate of lime. And as lime exists in considerable quantity in the older rocks, and when in union with carbonic acid is soluble in water

containing that acid, the action of such water in transporting carbonate of lime may account for the great quantity of this earthy matter in the stratified rocks.

426. When carbonic acid in union with an alkali (carbonate of soda), meets in solution a salt containing lime (as muriate of lime), magnesia (as muriate of magnesia), or iron (as sulphate of iron), carbonate of lime, carbonate of magnesia, or carbonate of iron will be formed. These are insoluble and will therefore be precipitated in the powdery form. Alum consists of sulphuric acid, potassa, and alumina. It is called sulphate of alumina and potassa. When this salt meets carbonate of potassa in solution, alumina is precipitated.

427. Potash, soda, and lime have a great affinity for carbonic acid and water. Hence the action of air, containing these two compounds, carbonic acid and watery vapour, in decomposing rocks containing these earthy matters. Carbonates of potassa, soda, or lime are formed. The two first are very soluble and would be easily washed away.

428. Organic matters consist chiefly of carbon, oxygen, and hydrogen. Carbon is not volatile nor fusible. It remains in the solid state unless united with oxygen, hydrogen, or some other element. But in most vegetable and animal matters there is not enough oxygen or hydrogen to carry off all the carbon in the aerial state. Hence the great quantity of carbon in coal and many strata, formed under water, where there was little free oxygen to remove the carbon in the liquid or gaseous form, and probably at great depths and at an elevated temperature. In this way, it is most probable that coal has been formed from vegetable remains under water.

429. Heat, acting on minerals or rocks, is capable of causing the integrant particles to enter into a different crystalline arrangement, to determine a crystalline structure where none previously existed, and even to alter the state of chemical combination, by causing a transfer among the constituent particles. Thus crystalline carbonate of lime is considered to be formed from sedimentary limestone acted on by heat. Sandstone of an evidently sedimentary character is found passing into a crystalline structure, where adjacent to basalt, the basalt being an igneous rock poured out on the sandstone in a state of fusion, and at a high temperature. Near the same rock coal is found converted into anthracite, having its volatile parts (oxygen and hydrogen) expelled by the heat. Fire-damp (carburetted hydrogen) is said to abound in those mines or parts of mines near a basalt dike, which, passing near the coal in a fused state and at a high temperature, has acted upon it in a manner similar to the action that goes on in the iron retorts at the gas-works, in which coal is exposed to heat.

430. When crystals are formed from a liquid, either having been in solution or fused by heat, they are large and well defined in proportion to the stillness of the liquid and the slowness with which they have cooled. Hence some striking differences in the appearance and internal structure of many lavas, similar in chemical composition, and perhaps all formed from one homogeneous liquid.

431. There appears to be a certain attraction between organic matter and some earthy matters which gives rise to certain kinds of petrifications, and to aggregations of particular substances in isolated

masses in some strata. Thus nodules of ironstone (carbonate of iron and sulphuret of iron) are frequent among the carboniferous strata, and nodules of flint in chalk. In the latter case there appears to be a certain attraction between the dead organic matter (which is believed to have been replaced by the flint), and the siliceous matter which formed the flint. The formation of the nodules of ironstone, is illustrated by the action of a nucleus in promoting the crystallization of a solid in a liquid. Any solid thrown into a liquid in which a crystallizable body exists in solution will promote its separation in the crystalline state. The particles collect on the solid nucleus, and the crystallization then goes on more rapidly. In the nodules of ironstone some organic remain is frequently found in the centre, which probably acted as a nucleus.

VII. DISINTEGRATION OF ROCKS, AND MODE OF FORMATION AND CHEMICAL COMPOSITION OF SOILS.*

432. It is conceived that all the solid matters of the earth existed once in the state of firm hard rock, and that loose earth or soil is formed from the breaking down of these rocks from the mechanical action of wind and rain, the chemical action of air and of water, the penetrating effects of the roots of vegetables, &c. Soils in many cases have been deposited from water holding various earthy matters in suspension, as in situations where a river frequently overflows its banks, and, holding finely

* The word "soils" is here used in opposition to rocky masses, which have formed the subject of the preceding sections. Here we shall treat of the powdery substances, sand, earth, &c., under the general name of "soils."

divided earthy matters mechanically suspended; deposits some of these at each overflow,—thus, in course of time, forming a soil, or *alluvial deposit*, as it is called.

Sand.

433. Sand, such as that which exists in such abundance in the beds of rivers and of the sea; on the shores of the various seas, and oceans, and neighbouring sandy beaches; in beds or strata in the earth; and in the extensive deserts in Asia and Africa;—consists almost entirely of silica. In general, sand has a slight tinge of a brownish-yellow colour, arising from the presence of oxide of iron. In some places, sand is found nearly white, or with a very slight tinge of yellow. Such is the sand procured at Lynn, on the coast of Norfolk, and at Alum Bay, in the Isle of Wight. From their great purity, these varieties of sand are largely used in the manufacture of glass. Sand is to be considered as formed by the breaking down of quartz rocks; or, as deposited from a mixture of sand, lime, and aluminous earth, mechanically suspended in water,—the sand, owing to its hardness and insolubility, not being so easily reduced to an impalpable powder and carried away in suspension (371). The sand is thus separated from the other matters with which it is associated.

434. Carbonate of lime also frequently has the appearance of sand, or enters largely into the composition of sand. In some soils the sandy part contains a considerable proportion of this earthy ingredient. In some shores the sand appears to consist almost entirely of carbonate of lime, derived from the broken-down shells of the various shell-fish.

which are so abundant in some places; the shells being gradually pulverized by the friction against each other caused by the action of the wind and waves.

435. The latter kind of sand is called calcareous; that composed of silica is termed "siliceous." The calcareous sand has not the hardness which distinguishes siliceous sand, and has the property of causing an effervescence (an appearance like that of ebullition) when dropt into muriatic acid, arising from the disengagement of the carbonic acid of the carbonate of lime in the gaseous form, the muriatic acid displacing it by combining with the lime.

Earth.

436. What is commonly called earth may be considered in two points of view, either as mixed or unmixed with decayed animal and vegetable matters. As originally produced from the decomposition of rocks, earth is destitute of any animal or vegetable matters; but these very soon enter into its composition, so that all common earth is more or less mixed with the remains of various animate bodies.

437. Earth, as that of soils, consists of small stones and hard sand:—earthy matters in a powdery state (finely divided), called the impalpable part of the soil;—various animal and vegetable remains undergoing chemical decomposition;—and small quantities of salts. The charcoal from these vegetable and animal matters undergoing decomposition, assists to give to soils the dark colour they possess; and where the decayed vegetable matters (of course containing charcoal) are present in very large quantities, the soils are nearly black, as in peat-mosses; charcoal, when detached from the other matters

with which it is in union in vegetables, that is, free or uncombined, being of a black colour. The earthy matters, however, make up far the greatest part of most soils, and there are four earths chiefly found in soils—silica, alumina, lime, and magnesia. Besides these, oxide of iron, oxide of manganese, and saline compounds are found in soils. The saline matters generally found there are common salt, sulphate of magnesia (Epsom salt), sulphate of iron (green vitriol), nitrate of lime, nitrate of magnesia, sulphate of potash, carbonate of potash, carbonate of soda.

In his Agricultural Chemistry, Sir Humphry Davy has described the composition and probable mode of formation of earthy soils from rocks. The following passages are extracts.

State of Combination of the Ingredients of Soils.

438. "The silica in soils is usually combined with alumina and oxide of iron, or with alumina, lime, magnesia, and oxide of iron, forming gravel and sand of different degrees of fineness. The carbonate of lime is usually in an impalpable form: but sometimes in the state of calcareous sand. The magnesia, if not combined in the gravel and sand of soil, is in a fine powder united to carbonic acid. The impalpable part of the soil, which is usually called clay or loam, consists of silica, alumina, lime, and magnesia; and is, in fact, usually of the same composition as the hard sand, but more finely divided. The vegetable or animal matters (and the first is by far the most common in soils) exist in different states of decomposition. They are sometimes fibrous, sometimes entirely broken down and mixed with the soil.

439. "To form a just idea of soils, it is necessary to conceive different rocks decomposed, or ground into parts and powder of different degrees of fineness; some of their soluble parts dissolved by water, and that water adhering to the mass, and the whole mixed with larger or smaller quantities of the remains of vegetables and animals, in different stages of decay."—*Davy*.

Mode in which Rocks crumble down to the State of Earth.

440. "Soils appear to have been originally produced in consequence of the decomposition of rocks and strata. It often happens that soils are found in an unaltered state upon the rocks from which they were derived. It is easy to form an idea of the manner in which rocks are converted into soils, by referring to the instance of *soft granite* or *porcelain granite*. This substance consists of three ingredients, quartz, felspar, and mica. The quartz is almost pure siliceous earth, in a crystalline form. The felspar and mica are very compounded substances; both contain silica, alumina, and oxide of iron; in the felspar there is usually lime and potassa; in the mica, lime and magnesia.

441. When a granitic rock of this kind has been long exposed to the influence of air and water, the lime and the potassa contained in its constituent parts are acted upon by water or carbonic acid; and the oxide of iron, which is almost always in its least oxidized state, tends to combine with more oxygen; the consequence is, that the felspar decomposes, and likewise the mica; but the first the most rapidly. The felspar, which is as it were the

cement of the stone, forms a fine clay; the mica partially decomposed mixes with it as sand; and the undecomposed quartz appears as gravel, or sand of different degrees of fineness.

442. "As soon as the smallest layer of earth is formed on the surface of a rock, the seeds of lichens, mosses, and other imperfect vegetables, which are constantly floating in the atmosphere, and which have made it their resting place, begin to vegetate;* their death, decomposition, and decay, afford a certain quantity of organizable matter, which mixes with the earthy materials of the rock; in this improved soil more perfect plants are capable of subsisting; these in their turn absorb nourishment from water and the atmosphere; and after perishing, afford new materials to those already provided: the decomposition of the rock still continues; and at length, by such slow and gradual processes, a soil is formed in which even forest trees can fix their roots, and which is fitted to reward the labours of the cultivator.

443. "In instances where successive generations of vegetables have grown upon a soil, unless part of their produce has been carried off by man, or consumed by animals, the vegetable matter increases in such a proportion, that the soil approaches to a

* These vegetables must have carbon, oxygen, and hydrogen for their growth: air and water supply the two latter, and they must derive a considerable part of their carbon or charcoal from the carbonic acid in the atmosphere, or perhaps from that in union with the lime or potassa in the new soil. In course of time they die and undergo decomposition (which will be explained in the next chapter). By *organizable* matter is meant the materials afforded by these dead vegetables, which are the chief food of other vegetables or organic bodies, and are thus termed the "organizable matter" of the soil.

peat in its nature; and if in a situation where it can receive water from a higher district, it becomes spongy, and permeated with that fluid, and is gradually rendered incapable of supporting the nobler classes of vegetables."—*Davy*.

444. Thus it is that, in the course of ages, air and water, by their chemical and mechanical effects, produce the extraordinary effect of wearing down the hardest rocks, the mountains, and the most durable monuments reared by man—to the state of earth or dust. Thus, sooner or later, buildings decay and moulder away; their inferior parts become worn away, and unable to support the great masses above. Hence, as Sir H. Davy has observed, the arch and the pillar and all perpendicular constructions are extremely liable to fall, more so than the pyramid, in which the broad basis of the lower parts must always form an adequate support for the tapering parts above. Hence the durability of the Egyptian pyramids. Another cause of the durability of the pyramids of Egypt and other monuments in that country is the almost total absence of rain, one of the chief agents in the gradual destruction of rocks and stones.*

* "Amongst the substances employed in building, wood, iron, tin, and lead, are most liable to decay from the operation of water; then marble, when exposed to its influence in the fluid form; brass, copper, granite, sienite, and porphyry, are more durable. But in stones, much depends upon the peculiar nature of their constituent parts; when the felspar of the granite rocks contains little alkali (potash) or calcareous earth (lime), it is a very permanent stone; but when in granite, porphyry, or sienite, either the felspar contains much alkaline matter, or the mica, schorl, or hornblende, much protoxide of iron (the oxide with the smaller quantity of oxygen), the action of water containing oxygen and carbonic acid on the ferruginous (iron) elements tends to produce the disintegration of the stone. The red granite, black sienite, and red porphyry of

445. In all these cases, it is to be observed that *the changes are produced chiefly by the action of carbonic acid and water upon the potash and lime of the mineral, and of the oxygen of the air upon the oxide of iron.* The latter action is well seen where buildings become stained with red or reddish-brown spots after being some time exposed to the air, and in the crust which forms on common whinstone.

446. In the leaning tower of Pisa, the marble pillars in the basement are scarcely altered, while the granite pillars have sustained considerable loss : this decay of the granite arises from the scales which fall off from their surface, which are covered with stains from the quantity of red oxide of iron formed. Here, the separation of the oxide of iron is the cause of the decay. These reddish-brown stains on stones exposed to the air are a well-known indication of the presence of iron.

447. The lime, then, in rocks and stones undergoing decomposition, becomes united to carbonic acid, and thus separated from its connexion with the other parts of the stone : the carbonate of lime thus formed is gradually dissolved and washed away by water containing carbonic acid, which is always the case with rain-water. The potash combines with carbonic acid, forming carbonate of potash which is very soluble and easily washed away by

Egypt, which are seen at Rome in obelisks, columns, and sarcophagi, are amongst the most durable compound stones ; but the gray granites of Corsica and Elba are extremely liable to undergo alteration ; the felspar contains much alkaline matter, and the mica and schorl much protoxide of iron."—*Davy's Last Days of a Philosopher.*

water. The oxide of iron separates in the manner mentioned above. These matters being thus detached, the cement is in a manner removed; the other matters are loosely held together, and, though comparatively insoluble, must yield and be broken down from the mechanical effects of wind, rain, hail, &c., and gradually crumble down.*

448. This disintegration of rocks is also very much promoted by the action of water in freezing. This is a prime mechanical agent in the breaking down of rocks. All rocks have cracks or fissures, perhaps originally formed from their contraction when cooling; thus in a manner created with the

* "Every thing belonging to the earth, whether in its primitive state or modified by human hands, is submitted to certain and immutable laws of destruction, as permanent and universal as those which produce the planetary motions.—The operations of Nature, when slow, are no less sure; however man may for a time usurp dominion over her, she is certain of recovering her empire. He converts her rocks, her stones, her trees, into forms of palaces, houses, and ships; he employs the metals found in the bosom of the earth as instruments of power, and the sands and clays which constitute its surface as ornaments and resources of luxury; he imprisons air by water, and tortures water by fire to change, or modify, or destroy the natural forms of things. But in some lustrums his works begin to change, and in a few centuries they decay and are in ruins; and his mighty temples, framed, as it were, for divine purposes, and his bridges formed of granite, and ribbed with iron, and his walls for defence, and the splendid monuments by which he has endeavoured to give eternity even to his perishable remains, are gradually destroyed; and these structures, which have resisted the waves of the ocean, the tempest of the sky, and the stroke of the lightning, shall yield to the operation of the dews of heaven, of frost, rain, vapour, and imperceptible atmospheric influences; and as the worm devours the lineaments of his moral beauty, so the lichens and the moss, and the most insignificant plants shall feed upon his columns and his pyramids, and the most humble and insignificant insects shall undermine and sap the foundations of his colossal works, and make their habitations amongst the ruins of his palaces and the falling seats of his earthly glory."—*Davy's Last Days of a Philosopher.*

principle of destruction within them. Into these and the pores water penetrates, and by its expansive power when freezing (247) enlarges these fissures, creates new ones, or breaks off fragments, which, exposed to the same chemical and mechanical actions, are gradually broken down to smaller fragments; and by such actions, and the attrition against each other in streams into which they are carried, are at length pulverized. By the action of running water they are transported in mechanical suspension to rivers, and deposited by them on their banks as an alluvial soil when they overflow, or carried out to the deep, where they are elaborated, subside in strata at the bottom, which are elevated by volcanic heat, emerge from the ocean, and reappear as land for the support of animal life in distant periods. In this way the hardest and most elevated mountain-peaks are gradually worn down, brought in grains to the ocean-level, diffused over the plains by rivers, or transported to nature's great workshop, the ocean.

Composition of Soils.

449. It is evident that soils must vary much, since the rocks from which they are formed are so different. Besides this evident cause of differences in soils, they must vary from being mixed by the operation of water; such are those which are formed of the deposit of rivers, known by the name of *alluvial soils*. These may be very different from soils which have been formed upon neighbouring rocks by their gradual decomposition. Some soils

are sandy; such are those which consist of about 7-8ths of sand; these scratch glass:—some are calcareous sandy, the sandy matter consisting chiefly of the carbonate of lime. In these there is an effervescence when the sand is placed in some diluted muriatic or nitric acid; others are clayey, containing from 1-6th to 1-4th of finely divided matter (the impalpable part of the soil), a large quantity of this being alumina, which does not effervesce with acids:—the term “loam” is applied to soils which consist of about 1-3d of finely divided earthy matter containing much carbonate of lime. Other soils are peaty, containing about one-half of vegetable matter.

450. The following analysis, taken from the above-quoted work of Sir Humphry Davy, will convey some idea of the

Composition of a Siliceous Sandy Soil.

“I obtained,” says Sir H. Davy, “from 400 grains of a good siliceous sandy soil from a hop garden near Tunbridge, Kent,

	Grains.
Water of absorption,	19
Loose stones and gravel (principally siliceous),	53
Undecomposed vegetable fibres,	14
Fine siliceous sand,	212
	— 298

298 grains of a good siliceous sandy soil from a hop garden near Tunbridge, Kent.

Of minutely divided matter, separated by agitation and filtration,

	Grains.
Carbonate of lime,	19
..... magnesia,	3
Matter destructible by heat (principally vegetable),	15
Silica,	21
Alumina,	13
Oxide of iron,	5
Soluble matter (principally common salt and vegetable extract),	3
Gypsum,	2
	81
	379
Loss,	21
	400

451. The following is the composition of a rich alluvial soil (449) from the banks of the river Parret, in Somersetshire, mentioned by Sir Humphry Davy.

Of nine parts of this soil, eight consisted of finely divided earthy matter, the other of siliceous sand; and the former, analyzed, yielded,

Carbonate of lime,	360 parts.
Alumina,	25
Silica,	20
Oxide of iron,	8
Vegetable, animal, and saline matters, 19	

452. In a turnip soil examined by Sir H. Davy, of nine parts, eight were siliceous sand, the other

part was the impalpable or finely divided matter. Its composition was therefore as follows :—

Siliceous sand,.....800 parts.

Finely divided Matter.

Carbonate of lime,.....	63
Silica,.....	15
Alumina,.....	11
Oxide of iron,.....	3
Vegetable and saline matter,.....	5
Moisture,.....	3—100

This soil was of a dry, loose, sandy texture.

453. In a good wheat soil examined by Sir H. Davy, he found three parts out of five to consist of siliceous sand, the other two being finely divided matter. The composition of the whole soil was as follows :—

Siliceous sand,.....150 parts.

Finely divided Matter.

Carbonate of lime,.....	28
Silica,.....	32
Alumina,.....	29
Animal or vegetable matter	
and moisture,.....	11

—100

This soil was of an opposite character to the preceding, being firm and coherent in its texture. In all cases it is the finely divided matters in the soil which give it firmness and tenacity, these properties depending on the carbonate of lime and alumina, chiefly on the latter.

454. These few specimens will convey a general

idea of the composition of soils. It will be seen that they vary much in chemical composition. Some soils, tolerably useful, contain nearly 6-7ths of silica, while others, equally valuable, will often be found containing only 1-7th of siliceous matter. The proportions of the other matters vary equally, and to these variations in their chemical composition are to be attributed their different qualities in reference to their power of supporting different kinds of vegetables.

455. It hardly belongs to chemistry to detail the qualities of the different kinds of soils. There are two great varieties—a dry, loose, and sandy soil ;—and a stiff clay soil. But there are a great many sub-varieties. The former contains too large a proportion of siliceous sand, the latter too great a quantity of finely divided matter, consisting chiefly of alumina and the carbonate of lime. In the sandy soil, the plant is not well fixed ; water, so essential to the growth of the plant, does not remain and adhere to the soil, but drains through too quickly ; thus also the decayed animal and vegetable matters, which should form the support of the crops grown on the soil, are washed away ; while, at the same time, from the too small proportion of the other earthy matters, the organic matters are not so well broken down and decomposed so as to be in a fit state for being taken up by the roots of the plants growing in such a soil. A stiff clay soil, on the other hand, opposes the entrance of air to the seed, and the free growth of the young roots, preventing them from penetrating by the cohesive nature of its particles, and not permitting water readily to drain through it, retains it and is apt to be wet. The

same is the case with a peat soil ; it is apt to be wet from not permitting the water it receives to drain through it readily. These are chiefly mechanical properties of soils. The chemical uses of the various earthy matters are not well understood, farther than that they assist in decomposing the organic matters in the soil.

456. Besides these, there are many other circumstances which affect the productiveness of soils ; such as the facility with which they are heated by the rays of the sun ; the length of time they retain their heat ; their power of absorbing moisture from the air ; the degree of evaporation from their surface ; their power in acting upon, combining with, and retaining the organized matter in the soil, which is greatest in rich soils, those which contain much alumina and carbonate of lime, and least in sandy soils, in which the organic matters, not being attracted by the soil, are decomposed by the air, or dissolved and removed by water ; the nature of the sub-soil ; and many others, upon which it would be out of place to insist here.

VII. REMAINING MATTERS WHICH ENTER INTO THE COMPOSITION OF THE EARTH—METALLIC ORES—NATIVE METALS—NATIVE SALTS—COMBUSTIBLE MINERALS.

457. The characters of the *metallic ores* may be seen in paragraphs 350-1-2. Although of very great importance to mankind, from the infinite number of uses to which the metals extracted from them are applied, they form but a small portion of the crust of the earth. The metals, when in the state of ores, are said to be *mineralized*, that is, in the condition

of brittle stones. The substances with which the metals are combined in the metallic ores are, in general, *sulphur, charcoal, and oxygen*. But many metallic ores are of a very compound nature, the metals in them being in some cases united with other metals, with silica, with alumina, with lime, &c. The metallic ores are distinguished from the metals by being brittle like common stones, but resemble them in being heavy and opaque, and in some cases have a resplendent lustre.

458. The metallic ores are frequently found in narrow fissures called *veins*, lying in a direction perpendicular to the horizon; and these fissures are generally filled with some crystalline mineral different from the rock in which the vein occurs. This mineral is most frequently calcareous spar (carbonate of lime), fluor spar (fluide of lime, a compound of fluoric acid and lime), heavy spar (sulphate of baryta), or quartz.

459. The ores of iron are the most abundant of the metallic ores; next, those of lead. The next, in point of abundance, are the ores of copper, zinc, tin, silver, antimony, arsenic, mercury, gold, platinum.

460. The *native metals* are still less abundant than the metallic ores. The general characters and properties of metals are described in paragraph 343. The metals found in the native state are, *iron, bismuth, arsenic, nickel, silver, copper, antimony, quicksilver, gold, platinum*. The two last mentioned metals, and a few others which are comparatively rare (tellurium, palladium, iridium, osmium), are found in nature only in the metallic state; never mineralized in the condition of metallic ores. DISC 578

461. The leading characters of the *native salts* and *combustible minerals* have been described in paragraphs 344-5, and the most interesting of these natural mineral compounds are mentioned there. Many of the combustible mineral bodies are found in the liquid state. They are more frequent, however, in the solid condition. They are brittle, like stones, and are not, in general, heavy, few being more than twice as heavy as water. The diamond is placed among the combustible minerals, being in its nature and chemical properties quite identical with charcoal.

462. Having now brought to a conclusion the general view of the chemical composition of the earth and of the chemical changes which it undergoes, it only remains to take a short review of the leading facts and principles brought out in this chapter.

RECAPITULATION.

The mineral kingdom consists of—1. *Rocks and stones*, which are hard, heavy, and brittle, incombustible, and insoluble in water :—exemplified by sandstone, whinstone, slate, flint :—2. *Sand*,—3. *Earth*, which are loose and powdery :—4. *Native metals*, mineral bodies which are rarely met with, and are characterized by being heavy, tough or tenacious, malleable and ductile, opaque, and perfectly insoluble in water :—5. *Native salts*, of a regular or crystalline form, not nearly so hard as rocks and stones, soluble in water, and consisting of

some acid in union with a compound of a metal with oxygen:—and, 6. *Combustible minerals*. These six divisions include all the various kinds of mineral bodies; but rocks and stones are not to be considered as essentially different from earth, sand and earth being merely pulverized rocks;—and these, rocks, stones, sand, earth (*earthy matters*), form the main bulk of the mineral constituents of the earth; the quantity of metallic ores, metals, salts, and combustible minerals, is trifling when compared with these. Earthy matters consist, in general, of some substance of a metallic nature in chemical combination with oxygen, forming an oxide; this oxide being in some cases in chemical union with some body of an acid nature; first discovered by Sir Humphry Davy, with potassa and afterwards with lime, clay, &c.: these being analogous to the common metallic oxides (as red lead), in their general composition. The leading earths are—1. *Silica*, the mineral ingredient of sand and flint, and the most abundant of the earths, distinguished by its hardness, durability, and insolubility in water and all acids except the fluoric:—2. *Alumina*, or earth of clays, distinguished by the softness and plasticity which it possesses when mixed with water; this earth is next to silica in abundance:—3. *Lime*, slightly soluble in water, caustic, and always found in nature in union with an acid (chiefly the carbonic), or with some other earthy matter:—and, 4. *Magnesia, baryta, strontia*, &c. Earthy matters also contain considerable quantities of the *oxide of iron* and of *potash*, and the oxide of manganese and soda are also occasionally found among rocks and earth. The rocky masses in the crust of the earth are

arranged in two great divisions, stratified and unstratified, and are composed of certain simple minerals, which are chiefly composed of silica and alumina, with smaller quantities of oxide of iron, lime, and magnesia, and minute proportions of other ingredients. The chemical composition of earth and soils is similar to that of rocks, the former being composed of the latter broken down and reduced to fragments or to powder by the chemical and mechanical action of air and water on the materials of the rock. The principal ingredients in the rock which are acted on are the potash, lime, and oxide of iron. These,—which, to a certain extent, act the part of cements to the various parts of the mineral in which they exist,—when they enter into new states of combination or are removed, no longer perform this office for the mineral, and it readily crumbles to pieces:—hence the decay of monuments and buildings, and the formation of loose earthy soils from firm hard rocks. These soils soon give support to various kinds of plants, and become mixed with decayed vegetable matter, and thus form the common soil of the agriculturist.

CHAPTER VI.

VEGETABLE AND ANIMAL BODIES.

463. We have now considered the chemical composition and properties of air and water, and of the solid earth on which we live, as far as we have been able to explore it. There are yet other bodies

around us for examination ;—the various kinds of animals which inhabit the earth,—and the vegetables, which grow so abundantly on its surface, adorn it, and form the support of the animal creation, for the higher class of which the whole seems to have been created. In taking a general view of the chemical composition of organized bodies (animals and vegetables), it may not be amiss to consider briefly the chief marks of distinction between them and inorganic or inanimate bodies:

Organic and Inorganic Bodies contrasted.

1. *Organic Bodies.*

464. Animate or organized bodies are characterized—1. By possessing an organic structure, that is, the particles of which they are composed are arranged together so as to form particular kinds of tissue,* and their tissue, by the various ways in which it is arranged, forms a greater or less variety of parts or organs, differing from each other in form and texture, and adapted to different uses—such as skin, bone, muscles, heart, brain, in animals ; and bark, wood, leaves, in vegetables.—2. Organized bodies are distinguished by their power of introducing into their interior parts new-matter collected from the substances around them, and differing from their own substance, separating what is of use from what

* The word "tissue" is applied here to the matter of organic bodies formed into a particular kind of structure, as that of small cavities, called *cells*, or tubes, called *vessels* : these are the two varieties of organic tissue. In common language, we speak of tissue as consisting of threads or fibres of various matters woven together: *organic tissue* means the particles which compose organic bodies woven into a connected bundle of cells and tubes by the influence of the vital principle.

is noxious or useless, and converting the former into tissue similar to their own ;—rendering it part of themselves (assimilating it), applying it to produce their growth, and to supply that waste of substance which takes place more or less rapidly in all organic bodies, dead or living.—3. Animate bodies have the power to a certain extent of resisting or suspending the chemical action of external agents and of their own elements upon each other, which tend to their destruction. This power they possess only while *life* remains within them : as soon as this principle has departed, chemical changes take place, producing decomposition or putrefaction, destruction of their form, a rapid decay or waste which is not supplied as before, and *finally*, the total disappearance of the remains, not a vestige being left to testify their former existence.

465. These three properties appear to be the essential features which indicate the presence of that mysterious principle called *life*. Wherever these characteristics are present, the body which possesses them is a *living being* or *animate body*, these terms applying equally to the animal and vegetable divisions of organized bodies.

466. There are other interesting peculiarities in organized bodies.—4. They have the power of forming a being of the same nature as themselves. 5. They decay and die at some definite period, the same in the same kind ; and (apparently) not from the action of external forces, but from the simple exhaustion of their organs ; being then decomposed, that is, resolved into the condition of inorganic matter, and obeying the laws to which it is subject. 6. Their component parts are so mutually dependent,

that a small portion cut out cannot maintain a separate existence. 7. They consist of fluid and solid parts, intermixed according to a regular order. 8. Their chemical composition is complex. 9. Their bulk is limited in each kind. 10. Their external surface is smooth and rounded, seldom formed into a regular plane or angle. 11. They cannot be formed by artificial means.

2. *Inorganic Bodies.*

467. Inanimate or inorganic bodies, constituting the mineral kingdom, are very different. They are of a homogeneous structure, each being all solid, all liquid, or all gaseous; the form, arrangement, and chemical composition being similar through the entire mass. They grow (increase in size) by the addition of matter already similar to their own, and only at their external surface. They have no power of resisting external agencies. They have no power of reproduction. They have no definite period of decay, being capable of existing unchanged for an unlimited period when not subjected to any external destroying influence. Any part possesses all the characters which belong to the whole. They are of a simple chemical composition, unlimited in size, and rough and angular externally; and they may be formed by artificial means.

468. There is another mark of distinction between organic and inorganic bodies which well illustrates their chemical composition. It is this:—Animal and vegetable substances are in every case completely decomposed, and almost entirely dissipated in vapour, or as gases, when they are exposed to a red heat, an extremely minute quantity of ashes

being left ; while minerals in general and earthy matters are not so readily decomposed by heat, and do not become gaseous even by the most intense heat which can be produced. They may be melted, but they are not dissipated—there is always a great part of them left in the solid state. The tendency to *spontaneous decomposition* is also a distinguishing feature of dead organic substances. Every one knows how soon animal and vegetable matters are decomposed, evaporate, and disappear, when exposed to the air even at its usual temperature.

469. In general, mineral substances contain some leading element which characterizes the compound, and is very different from the principal element in the composition of other mineral compounds. Thus, lime is the base (or principal ingredient) in carbonate of lime (as chalk or marble), and, in point of chemical composition, distinguishes carbonate of lime from carbonate of potash, which has for its leading ingredient potash, a very different substance from lime. Gypsum has lime for its base, while green vitriol has oxide of iron, and blue vitriol oxide of copper, all these being in union with sulphuric acid, and differing in the nature of the substance combined with the acid. But organic bodies, however different, consist of the same kinds of matter, differing chiefly in the *proportions* in which these different kinds are present. Thus, *woody fibre*, which forms the greater part of all vegetables, *starch*, *sugar*, *gum*, and *vinegar*, consist of the very same materials, carbon, oxygen, and hydrogen, the differences between these substances arising either from the very minute differences which exist in the *proportions* of their elements, or from the presence of

some earthy matter, the proportion of which is, however, exceedingly small. Hence the ease with which many substances derived from the organic kingdom of nature can be converted into each other. A matter resembling starch may be formed from sawdust—starch can be turned into sugar—sugar into spirituous liquors—and these last into vinegar.

470. The difference between organic and inorganic bodies pointed out in the preceding paragraph, though generally observed, does not hold universally; for many mineral bodies, as felspar, hornblende, mica (see page 256), contain nearly the same leading ingredients (silica and alumina), the differences arising from the proportions of these, or from the presence of small quantities of other matters. And many other inorganic bodies, such, for example, as the compounds of nitrogen and oxygen, of carbon and hydrogen, varying considerably in properties, owe these differences to differences in the proportions of their component parts. As far as we know at present, however, it seems to be generally true, that in the organic kingdom the various substances which we procure from that source, and which in their properties differ very much, are composed almost entirely of the same elements, and vary little in the proportions of these elements.

471. We have seen that the mineral kingdom, notwithstanding the infinite variety of objects which it presents to our view, is composed of one or two principal ingredients, silica, alumina, and carbonate of lime, with a few other matters sparingly scattered through the mass. It is the same with animals and vegetables: however different from each other, however varied the forms in which we find them,

they are chiefly composed of four matters, which, by their union in different proportions, give rise to this great variety.

472. These four elements are substances of which we have already acquired some knowledge, namely, *carbon or charcoal, oxygen, hydrogen, and nitrogen*. The latter is not frequent in vegetables, and this, in a chemical point of view, forms a mark of distinction between animals and vegetables.

473. The other matters, which are present in small proportions in vegetables and animals, are phosphorus, sulphur, potash, lime, silica, iron, and occasionally a few other bodies analogous to these.

Animals and Vegetables Contrasted.

474. Sensibility, or the consciousness of existence, a sensation of impressions from without, and a power of voluntary locomotion, are the general characteristics of animals; vegetables are endowed only with a dull and limited sensation, and what is termed **IRRITABILITY**, a power of simple contractile motion on the application of some external stimulus.

475. As a general distinction between the three kingdoms of nature, the concise definition by Linnaeus is admirable, "Minerals grow; vegetables grow, and live; animals grow, live, and have feeling." *These distinctions, so well marked in the higher orders of animals and vegetables, as a tree, a man, disappear in the lower grades, where the animal and vegetable kingdoms approximate; and there are some species about which there is doubt whether they should be reckoned animals or plants. Many of the polypi are destitute of any power of locomotion, and appear to be void of sensibility;*

while some of the algæ possess irritability and consequent mobility in a very high degree, and have much of the character of animals. The sponges (porifera), apparently the simplest in structure of the various tribes of animals, approximate very closely to vegetables. The *polypi vaginanti* were placed among vegetables in Tournefort's arrangement; more lately, some species, formerly supposed to be confervæ, have been removed from vegetables, and placed among the simplest tribes of animals. Some botanists hold the singular doctrines, that, in certain cases, metamorphoses of plants into animals, and *vice versa*, take place; and that the animal kingdom approaches the other two in some of the simpler algæ which have somewhat of a crystalline texture.

476. This difficulty of distinguishing between plants and animals is found only in the lower tribes of each. In the HIGHER ORDERS, the differences are marked, as the following comparison will show:—

PLANTS	ANIMALS
Are fixed, having no power of locomotion, no system of contractile muscles.	Have a set of contractile fibres (muscles), and hence the power of locomotion.
Have no consciousness of existence, no experience of any wants, no power of selecting food.	Have consciousness of existence, a feeling of wants which they endeavour to supply, a power of selection among the materials they find.
Insensible to all external impressions.	Possessed of a nervous system, and senses, for communication with the external world.

PLANTS

Can live on inorganic matter alone.

Have no internal cavity or sac (stomach) for receiving their food.

Contain much solid matter.

Consist of few elements.

Carbon (charcoal) their leading element, and contain little or no nitrogen.

Slowly decomposed when dead.

ANIMALS

Feed only on organized bodies, animals, and vegetables.

Have a stomach, or internal receptacle, into which the food is received.

Contain a large proportion of fluids.

Elements more numerous.

All contain a large quantity of nitrogen.

Decompose rapidly when dead.

I. CHEMICAL COMPOSITION OF VEGETABLES.

477. In examining the composition of air and water, we have seen that recourse has been had to the assistance of *fire* to enable us to discover the elements of which they are composed. The same powerful agent is employed in showing the composition of vegetables. By exposing them to the effects of a strong heat, the various elements of the vegetable are separated from each other, or made to unite in a way different from that in which they are united in the vegetable,—to enter into new arrangements, in which we can examine them more easily.

Effect of Fire on Vegetables.

478. If a piece of wood be burnt in an open fire, a great deal of bright white flame is produced ; and if we stop the burning at a certain point, it will be

found that the wood retains its original form, but has slightly diminished in size, and become somewhat shrivelled, and that it has also become black. If the wood, however, be allowed to burn for some time, and air be freely supplied to it, it will be entirely burnt away, or will disappear, with the exception of a few grayish-white ashes, which remain, being incombustible.

479. Here it will be understood that the matter composing the wood which has disappeared has not been destroyed or annihilated by the burning, that it has merely *altered its form*: when in the state of wood, being solid, opaque, and capable of producing an impression on the sense of sight;—when the wood disappears, this matter has become aërial, transparent, and colourless, so that it does not affect the eye, but mixes as an invisible gas with the surrounding air. In all our operations with matter, we merely produce a change in the form, situation, or some of its properties; we cannot create or destroy a single particle. Matter is perfectly indestructible. When, therefore, we speak of any substances being destroyed, consumed, or dissipated, all that is meant is that they have become gaseous and invisible, and have flown away, that is, ascended in the air in consequence of their lightness, or in obedience to the law of the diffusion of gases.

480. From this effect of heat, then, we learn that wood (and all other parts of vegetables are somewhat similar to wood in chemical composition) is composed of a large quantity of combustible matter, and a few ashes or earthy matters which do not burn. The combustible matter has assumed the

gaseous form and disappeared. When the wood has been so far burned as to have entirely become black, it is found that it has become much lighter : it is now *charcoal* : much of the component parts of the wood have flown away, in the form of transparent colourless gas, and, in order to examine the nature of these matters in the wood which became aërial when burned in this way, there must be some method of collecting them for examination.

481. This is done by exposing the wood to heat in a retort, in which it may be burned without being in contact with the air ; or with so small a quantity of air in proportion to the mass of wood that it does not at all affect the operation so as to require to be taken into account in a general estimate. The gases or other matters which arise from the wood can be collected by means of vessels communicating by a tube with the retort in which the wood is burned. This operation is known among chemists by the name of *destructive distillation*, the matter examined being destroyed by the heat, and some of the new substances formed being collected in a manner similar to that in which the products are collected in the operation of distillation (302).

482. As a considerable heat is required to effect the decomposition of the wood, an iron retort is used for this purpose, and it must be heated by being placed in a furnace or in a fire in a grate. Its construction and general form are somewhat similar to that of a common glass retort (99). The tube, however, is made moveable, fitting in tightly at the neck, so that the materials can be introduced directly into the body of the retort, after which

the tube is fitted in, and then the apparatus is used exactly as a retort. This retort may be used for preparing gases (the extremity of the tube being adjusted in the manner shown in the figure in page 70); or for distillation (302), condensing the vapours by cold. If the vapours require to be collected in water, the same arrangement of apparatus will serve, some water being placed in the receiver.— This is the case with many vapours. The vapour of water is condensed into water by being merely cooled: and all that is necessary to be done, in order to collect it and condense it, is to cause it to pass into a vessel kept cool by cold applications at the outside of the vessel. But there are many vapours which do not readily turn into liquids by being merely cooled, though they readily combine with water: such vapours are condensed by causing the extremity of the tube which conveys them from the materials which produce them to pass into a vessel containing water, which absorbs them as they come into contact with it. Many substances prepared by distillation are collected in this manner. The water does not alter much the properties of the matter thus collected, and, by giving it the liquid form, enables us to discover and make use of these properties.

483. When wood is placed in an iron retort in this way, and exposed to a red heat, water, which forms a principal part of the juices of the wood, comes away in the form of steam. If the open extremity of the tube be immersed in water, this water will soon be observed to turn sour and acquire a sharp acid taste, somewhat resembling that of common vinegar, but having much of the odour of

tar ; some tarry and oily matters will also come over from the retort ; and a quantity of gases which are not absorbed by water are disengaged : these may be collected in jars on the pneumatic trough.

1. *Charcoal a component Part of Vegetables.*

484. If what remains in the retort be now examined, it will be found to be a light black solid, nearly of the same size, and of the same form as the piece of wood used. It is charcoal (carbon), and, with the exception of a small quantity of earthy matters which it contains, is tolerably pure charcoal. Charcoal forms the greater part of wood, and almost all the solid parts of vegetables, and is therefore considered the *base*,* or chief ingredient in the composition of vegetables. Charcoal, in chemical language termed carbon, is a simple substance, in the form of a black solid when pure, and an abundant ingredient in both animals and vegetables.

485. The leading property of charcoal is its combustibility, by which, it will be borne in mind, is meant (in all ordinary cases) the power of a substance to enter into chemical union with oxygen, and produce heat and light at the same time. When charcoal burns in the air, a dull red heat is produced, and in general little flame or only a pale blue flame. Cinders from a coal-fire, or coke, such as is procured from the gas-works, become red-hot when burning, and give out a considerable quantity of heat, but little light or flame. They consist of

* The term "base" is applied in chemistry to what is considered the leading ingredient in a compound substance. Carbon is said to be the base of vegetables, lime the base of carbonate of lime, iron the metallic base of oxide of iron, sulphur the base of oil of vitriol, which consists of sulphur and oxygen.

little else besides charcoal and earthy matter or ashes. In common air, charcoal burns rather dully, the oxygen, which supports the combustion, being so largely diluted with nitrogen; but if care be taken to supply it freely with air, it will entirely disappear, with the exception of a few ashes. The same takes place, but more rapidly, and with a brilliant white light, if the charcoal be made to burn in oxygen gas.

486. In both cases, the charcoal, with the exception of the minute quantity of ashes, entirely disappears: it loses its solid form by uniting with the oxygen, becomes gaseous, forming with the oxygen *carbonic acid gas*, the aerial matter, which has already been so often alluded to, as existing in the atmosphere, in many kinds of water, and in the earth in union with lime and other earths, as in chalk. If a few fragments of charcoal be enclosed in a small cage made of copper wire, and, while burning, be held suspended in a long jar, on removing the charcoal and examining the gas by the test of lime-water, as mentioned in par. 145, it will be found that the lime-water will become muddy, indicating the presence of a large quantity of carbonic acid, which must have been formed by the combustion of the charcoal.

487. This matter then, charcoal or carbon, which, when strongly heated in contact with air or oxygen, unites with the oxygen and forms carbonic acid gas, losing its opacity and solidity;—this black matter makes up a large part of all vegetables, particularly the hard or woody parts. It is not black in vegetables, because in the state of chemical combination with other matters in which it exists in them, it

bears a different relation to the rays of light ; but when by itself, it assumes this colour. Starch, sugar, gum, and other vegetable matters (such as a potato), when treated in a similar manner, are resolved in the same way into various matters which come away from, and charcoal, which remains in, the retort.

488. Having thus seen what is *left* when wood is burned in a situation where it is not freely exposed to the air, let us now examine the matters which come away.

489. First, water, which is an abundant ingredient in the juice of all plants, comes away in the form of watery vapour or steam. Some of the watery vapour which is produced is, it is most probable, formed by the union of part of the oxygen and hydrogen of the wood.

490. Then a matter comes over, which is absorbed by water, and renders the water sour or sharp-tasted. In taste and smell it strongly resembles tar and vinegar. When this water is subjected to various processes, by which the tarry matter which comes over at the same time is removed, and strengthened by boiling, so that part of the water passes away in vapour, an acid matter is procured, exactly of the same nature as the acid which exists in vinegar and gives this liquid its peculiar properties. When strong and pure, this liquid is called *acetic acid*, this term being derived from the Latin word for vinegar. It is also called *pyroligneous acid*, from the Greek $\pi\upsilon\rho$ (*pur*), "fire," and the Latin word *lignum*, signifying "wood," expressive of the manner in which it is procured. The action of heat upon the wood converted part of its component parts into the vapour of

vinegar; this vapour was expelled from the retort, passed through the tube, and was absorbed by the water into which the extremity of the tube dipped.

2. *Oxygen and Hydrogen component Parts of Vegetables.*

491. Acetic acid, when strong, is easily turned into vapour, and this vapour is inflammable, taking fire and burning with a white flame. When it burns, carbonic acid gas and watery vapour are produced, showing that the vinegar must have contained carbon and hydrogen. The carbonic acid and watery vapour contain only carbon, oxygen, and hydrogen. The oxygen might have been here procured from the air; it is derived partly from this source and partly from the vapour. Acetic acid, when made to pass through red-hot tubes, where it is not in contact with air, is partly decomposed; and in this case also carbonic acid and watery vapour are among the substances which are produced. The oxygen in these must in this case have been derived from the acetic acid itself, so that we here see that the wood contains also a considerable quantity of oxygen. These three elements are the components of acetic acid. Thus, it would appear that all the carbon has not been left behind. Some of it has passed over along with oxygen and hydrogen in the form of vapour of vinegar, showing that wood contains *oxygen* and *hydrogen*, besides carbon. Acetic acid consists, in a hundred parts, of

Carbon,	.	.	46.83
Hydrogen,	.	.	6.35
Oxygen,	.	.	46.82

492. The same may be shown by the examination of the gases, which, it has been mentioned, come away from the retort in which the wood is exposed to heat. Although apparently only one gas issues from the tube, there are a number of different gases formed, which are mixed together in the aerial matter which passes out of the tube, and is collected for examination in the jars of the pneumatic trough. If a flame be applied to the gas as it issues from the tube, the gas will take fire, being of a very inflammable nature, and will burn with a whitish flame, similar to that with which wood burns openly in the air. It is found that, during the combustion of this gas, as in the case of the burning of the vapour of acetic acid, part of the oxygen of the air is consumed and converted into carbonic acid gas and watery vapour, showing that the gas must have contained carbon and hydrogen. Here we derive another proof of the existence of hydrogen in vegetables. This gas consists chiefly of these elements (carbon and hydrogen), and is called *carburetted hydrogen gas*. It is very similar in its nature to coal-gas, which indeed is formed in the same way, —by exposing coal to a strong heat in iron retorts,—coal being nearly of the same chemical composition as wood. Besides this gas (the carburetted hydrogen), carbonic acid gas, hydrogen gas, and carbonic oxide* gas are found in gas thus obtained from wood. The tarry and oily matters which are procured at the same time, are proved in a similar manner to consist of charcoal and hydrogen. Thus, the whole of the

* Carbonic oxide gas is a compound of carbon and oxygen, but containing only half the quantity of oxygen which exists in carbonic acid gas, although consisting of the same ingredients.

wood, with the exception of the gray ashes which remain after the charcoal is burned, consists of charcoal, oxygen, and hydrogen.

We may now consider briefly what goes on when wood is burnt freely in contact with air.

493. In this case, as in the other, the effect of the heat is to render the elements composing the wood incapable of existing any longer in the state of wood. Repulsion is established between their particles, and they fly off in the gaseous form. The hydrogen and so much of the carbon enter into union as carburetted hydrogen gas, but being at a very high temperature, and in contact with oxygen, supplied in unlimited quantities, this gas is burned at the instant of its formation; for its elements have an affinity for oxygen, and when exposed to a great heat, separate from each other and unite with oxygen, or undergo combustion, and thus produce the white flame which arises from the burning wood. This combustion of the carburetted hydrogen produces carbonic acid gas and watery vapour in the same way as described in the preceding paragraph. The production of carbonic acid gas by the burning of wood may be easily shown in the manner described in par. 145. The formation of watery vapour is seen when a few wood-shavings (however dry) are burned and the flame is made to strike upon a cold surface, as that of stone or marble. It becomes dim and covered with moisture from the condensation of the watery vapour by the cold stone.

494. The manner in which the carbon, oxygen, and hydrogen are disposed of is as follows:—The hydrogen of the wood partly unites with its oxygen and forms watery vapour, and partly unites with so

much of the carbon, forming carburetted hydrogen gas, the hydrogen in this gas being ultimately turned into watery vapour, as explained in the preceding paragraph. The oxygen of the wood unites with part of the carbon, forming carbonic acid gas, and with part of the hydrogen, forming watery vapour. The charcoal of the wood is consumed, partly by hydrogen, which converts it into carburetted hydrogen (the carbon in this gas being finally resolved into carbonic acid gas), partly by the oxygen of the wood, which forms it into carbonic acid gas, and chiefly by the oxygen of the air, which, if freely supplied, soon converts the remaining charcoal into carbonic acid. Hence, in an open fire, the charcoal disappears, and nothing is left but a few ashes.

495. But the case is very different when the wood is exposed to heat in a vessel where it has not free access to air. When the oxygen and hydrogen and so much of the carbon have combined and come away in the form of inflammable gas, vapour of vinegar, tarry matter, &c., there is not any hydrogen remaining to turn the remaining carbon into inflammable gas, and thus convey it away; there is not any oxygen left to turn it into carbonic acid gas:—thus, a great quantity of the charcoal, from the absence of oxygen or hydrogen, which would convert it into carbonic acid or carburetted hydrogen, and convey it out of the retort in the gaseous form, must remain in the retort in the solid form; for carbon, by itself, is not turned into vapour by any degree of artificial heat.

496. When the wood is exposed to heat in the open air, so much inflammable gas is formed, and meeting with oxygen, burns, and produces the flame.

When the wood is burned, excluded from the air, this inflammable gas is also formed then, but, not meeting with oxygen for its combustion, it continues and comes away in the state of inflammable gas. Also, there is not so much inflammable gas formed when the wood is exposed to heat without the access of air, because part of the carbon and hydrogen are in the vapour of vinegar and tarry matter which are formed. There is no acetic acid or tarry matter formed when the wood burns in the air, for the oxygen of the air converts all the carbon and hydrogen into carbonic acid gas and watery vapour.

497. Occasionally, with some kinds of wood, and often with peat, a small quantity of vapour of vinegar is produced even when burned openly in the air, and hence arise the acrid fumes which affect the eyes when near a wood or peat fire. In general, however, only a very small quantity of vapour of vinegar is formed during the combustion of vegetables freely exposed to the air.

498. The ashes which remain when wood is burned consist chiefly of silica, lime, and carbonate of potash, matters taken up from the soil in which the tree or plant grew. They form a very small part of the ingredients of the vegetable.

499. In all vegetables charcoal is the most abundant ingredient, and may be considered the principal one. It is the charcoal which determines their form and gives them their stability and firmness, resembling somewhat in this respect the bones of animals. It is the charcoal which forms the chief ingredient in *vegetable mould*, the dark substance formed by the decomposition of plants, which forms the main support of living plants growing on the earth.

500. We have thus seen that vegetables are com

posed chiefly of carbon, oxygen, and hydrogen. Some particular parts of a few plants contain nitrogen, but this element is rarely met with in the vegetable kingdom.

501. There are many matters which, by particular processes, are easily procured from vegetables ; such are sugar, starch, gluten, oils, resins, gums, spirituous liquors, and peculiar acids. These are called proximate principles of vegetables.

502. A curious general principle (not without exceptions however) with regard to the composition of these matters was pointed out by some French chemists, which may be mentioned here. It is this :—All *acid matters* found in or produced from vegetables, as tartaric acid, citric acid (the acid of lemons), contain a great quantity of oxygen combined with the hydrogen and carbon,—*more oxygen than would be necessary to form water with the hydrogen, or, more than 8 parts of oxygen to 1 of hydrogen.* All spirituous, oily, or resinous matters obtained from the vegetable kingdom, contain a great quantity of hydrogen united with the carbon and oxygen,—*more hydrogen than would be sufficient to form water with the oxygen, that is, more than 1 part of hydrogen to 8 of oxygen.* Inflammable matters are an example of this. Caoutchouc contains carbon and hydrogen without any oxygen. All vegetable matters which are characterized by being mild and inert in their nature, seem to contain the *oxygen and hydrogen in the proportions in which these elements exist in water, 1 of hydrogen to 8 of oxygen : such are wood, gum, starch, sugar.*

503. The following tables illustrate the statement in the preceding paragraph, and show the general composition of vegetable matters.

1. *Vegetable Matters with a large Proportion of Hydrogen.*

	Olive Oil.	Linseed Oil.	Resin.	Caoutchouc.
Carbon,	77·213	76·044	75·944	90·
Hydrogen,	13·36	11·351	10·719	9·12
Oxygen,	9·427	12·635	13·337	0·88
	100·	100·	100·	100·

2. *Vegetable Matters with a large Proportion of Oxygen.*

	Tartaric Acid.	Citric Acid.
Carbon,	35·980	41·369
Hydrogen,	3·807	3·800
Oxygen,	60·213	54·831
	100·	100·

3. *Vegetable Matters with the Hydrogen and Oxygen nearly in the Proportion in which these Elements exist in Water.*

	Sugar.	Wheat Starch.	Potato Starch.	Gum Arabic.	Lignin.
Carbon,	42·85	43·55	44·25	42·23	51·45
Hydrogen,	6·35	6·77	6·67	6·93	5·82
Oxygen,	50·8	49·68	49·08	50·84	42·73
	100·	100·	100·	100·	100·

Lignin constitutes the hard fibrous matter of wood ; 96 parts in a hundred of wood consist of lignin.

3. *Decomposition or Putrefaction of Vegetables.*

504. All vegetables, when the principle of life has departed from them, begin spontaneously to be decomposed (to putrefy). The elements which enter into the composition of plants, when left entirely to the disposal of their chemical affinities, have a tendency to separate from each other, and form new compounds, very different from those which compose

the living plant.* This is termed the “spontaneous decomposition” of vegetables. The substances formed by the new arrangement of the elements of the vegetable are aërial and colourless;—hence the entire disappearance of the vegetable, as if it had been totally annihilated when life ceased to preserve its particles together in the vegetable form.

505. The compounds formed when the vegetable dies and putrefaction goes on are, carbonic acid, water, carbonic oxide, and carburetted hydrogen. The two former are the chief results of the decomposition; the two latter are formed more sparingly, and principally when there is not a free supply of oxygen to the substance undergoing decomposition. The carbon and hydrogen of the plant have a constant tendency to unite with oxygen and form carbonic acid and water. Now, there is never present in the vegetable a sufficient quantity of oxygen to convert *all* the carbon into carbonic acid, and *all* the hydrogen into water; hence, if there be not a sufficient supply of oxygen to produce these compounds presented from external sources, as from the air, the two other matters are formed, one of which (carbonic oxide) requires a less quantity of carbon than the carbonic acid, while the other (carburetted hydrogen) requires no oxygen, consisting of carbon and hydrogen.

506. In vegetables which decay under water, carburetted hydrogen is abundantly formed; hence arises the gas which is found so plentifully in sum-

* In speaking here of the spontaneous decomposition of vegetables, the entire vegetable is alluded to, not particular products formed spontaneously by vegetables, or procured from them by artificial processes; such as gum, resin, caoutchouc, sugar, oils, &c. These and many other vegetable substances can exist for a very long period without undergoing any change.

mer in stagnant waters containing quantities of putrefying vegetables.

507. The spontaneous decomposition of vegetables goes on most rapidly when they are exposed to the air, kept moist, and preserved at a degree of warmth higher than the usual temperature of the atmosphere. Putrefaction is retarded or almost prevented if the vegetable be dried, so that its own moisture is expelled, carefully excluded from air and moisture, and kept cold. The influence of heat in promoting the decay of vegetables depends upon the repulsive power it possesses, by which it disposes the various elements to assume the gaseous form. Animals and vegetables are frequently found in snow or ice in a high state of preservation.

508. Such are the changes which go on in the dead plant. That mysterious agent, LIFE, is able, by its peculiar power, to control and overcome the chemical attractions which tend to produce these changes, and retains these elements in that state of combination best adapted for the performance of their proper functions: at the moment, however, in which life ceases to superintend the exercise of these functions, they cease, and the chemical attractions, no longer restrained by the vital principle, obtain full sway. The carbon, oxygen, and hydrogen, formerly existing in the state of wood, bark, leaves, fruit, or seeds, obey the laws of chemistry, return to the state of carbonic acid, water, or inflammable gas, mix with the earth and atmosphere, afford nutriment to new plants, again form leaves, flowers, and all the beautiful and diversified organs of the vegetable creation—again wither and decay, and return to the soil to supply new generations, and continue the same series of unceasing revolutions.

II. CHEMICAL COMPOSITION OF ANIMALS.

509. In examining the composition of animal substances, we shall find that, like vegetable matter, they are composed of only a few elements, the infinite variety observed depending on the different proportions in which these elements are combined.

510. As a specimen of animal matter, we shall take the example of *bone*. When bone is exposed to a strong red heat for a while, a number of gases are given off, part of which take fire and produce flame, and nothing remains but an earthy matter retaining the form of the bone. This earthy matter is incombustible, and, when the bone has been properly burnt, is of a pure white colour. It consists of phosphorus, oxygen, and lime. The phosphorus and the oxygen are in union together in the form of an acid, called phosphoric acid, and this phosphoric acid is combined with lime. In trees and plants we have seen that the charcoal acts the part of a basis or support, which gives hardness and firmness, and serves as a point of attachment for the other parts. It is the same with the bones of animals—and it was necessary that they should be formed of some matter which would bear a great deal of pressure, and resist the very strong forces which are applied by the muscles. This is afforded by the earthy or stony matter called the *phosphorus of lime*, which, when bound together by the cement of animal matter which bones contain, form a support for the animal, exceedingly strong and tough in texture.

511. This animal matter, which forms the cement of the earthy particles of the bone, consists of *carbon, oxygen, hydrogen, and nitrogen*, and it is nearly the same composition as the other parts

animals, such as muscle, skin, blood, and so on. Now, in burning the bone, the carbon and other matters (except the phosphate of lime) unite with the oxygen of the air and fly off in the form of gas; —the earthy matter is left, just in the same way as the carbon, hydrogen, and oxygen fly off from wood when burnt, and leave the grayish-white ashes. But, when the cement has flown away, the earthy matter is exceedingly brittle, like a wall built without mortar, and readily crumbles down.

512. What has been here called the animal matter may be procured separately by steeping the bone in diluted muriatic acid. This muriatic acid unites with the lime of the phosphate of lime, and forms with it a compound (muriate of lime) which is dissolved by the water. The phosphoric acid is at the same time detached from the lime, and also dissolved by the water. Thus the earthy matter is altogether extracted from the bone, when the bone appears in the state of a soft flexible mass like gristle, still retaining the form which it first possessed; for the muriatic acid has little or no effect on the animal matter which is united with the earthy matter of the bone.

513. The shells of some animals, which serve to them nearly the same purposes as the bones of other animals, namely, to give firmness and stability, and afford fixed points for the muscles to act upon, consist also of an earthy matter in union with a cement of animal matter, the former, however, being in larger proportion than the earthy matter in bones. The earthy matter in these consists of carbonate of lime, not of phosphate of lime. This may be easily seen by dropping an oyster-shell into a glass containing some diluted muriatic acid, when an effervescence (*escape of gas in bubbles*) will be observed,

which, it will be recollected, is an indication of the presence of carbonic acid in an earthy matter (435). When the earthy matter of bones is treated in a similar manner, no effervescence takes place; the phosphoric acid disengaged remains in the water.

514. The following tables will illustrate the composition of animal substances. The first shows the composition of three substances, called proximate principles of animal organic bodies, abounding in them, and being easily procured from them. The second shows the composition of the blood, the fluid from which all the other parts are secreted :—

	Fibrin.	Albumen.	Gelatine.
Carbon,	53·36	52·883	47·881
Hydrogen,	7·02	7·54	7·914
Nitrogen,	19·934	15·705	16·998
Oxygen,	19·686	23·872	27·207
	100·	100·	100·

COMPOSITION OF THE BLOOD.

Water,	785·590
Fibrin,	3·563
Colouring Matter,	119·626
Albumen,	69·415
Crystalline Fatty Matter,	4·30
Oily Matter,	2·270
Extractive, Soluble in Water and Alcohol,	1·920
Albumen Combined with Soda,	2·010
Chloride of Sodium, Chloride of Potassium, Carbonates, Phosphates, Sulphates of Potassa and Soda,	7·304
Carbonates of Lime and Magnesia,	1·414
Phosphates of Lime, Magnesia, and Iron, Peroxide of Iron,	
Loss,	2·586
	1000·000

The colouring matter, which, according to the above analysis, forms 119 of 1000 parts of blood, consists of the same ingredients as fibrin and albumen (carbon, hydrogen, nitrogen, oxygen), and nearly in the same proportions, with the addition of a little oxide of iron, 0·7 in 100 parts of the colouring matter.

Spontaneous Decomposition of Animal Substances.

515. Like vegetables, animals, as soon as the vital principle has departed from them, are solely obedient to the laws of chemistry,—they lose their form and entirely *disappear*—the elements of which they are composed enter into new states of combination, and they *decay* or *rot*, partly mixing with the air as transparent invisible gases, and partly crumbling down to powder, which mixes with and cannot be distinguished from the surrounding earth:—and, as their elements are more numerous than those of vegetables, the chemical attractions which cause their decomposition are more numerous, and they decay more rapidly.

516. From the presence of nitrogen, ammonia (popularly, hartshorn) is formed during their putrefaction. Ammonia consists of hydrogen and nitrogen: as formed during the decomposition of animal substances, it is in union with carbonic acid, in the state of *carbonate of ammonia*. Carburetted hydrogen and small quantities of two other compounds of hydrogen (sulphuretted hydrogen and phosphuretted hydrogen gases) are formed during the decomposition of animal matters. The chief products of the decomposition are water, carbonic acid, and carbonate of ammonia. With the exception of the *carbonate of ammonia*, the products formed are

similar to those produced by the decomposition of vegetables, carbonic acid, water, and carburetted hydrogen, the two former being the principal products.

517. The bones and shells of animals, on account of the earthy matter which they contain, endure for a very long period ; but these too have their allotted time, and, sooner or later, must yield to the crushing influence of those destroying powers which neither spare the forms of beauty and grandeur into which Nature moulds her materials, nor venerate their remains. Gradually, as the animal matter or cement of the bones is decomposed (from the action of its elements on each other assisted by the effects of air and moisture) and separated from the earthy matters, they also moulder away and mix with the surrounding earth. The loosened atoms, alone spared amid the universal ruin, the strange witnesses and actors in those changes in which FORMS are alternately created and destroyed, obey the laws of matter, and enter into a new series of combinations ; the last outline of the animal form is destroyed ; the most enduring memorial of animal life disappears ; and thus is fulfilled the doom of man,

“Dust thou art, and unto dust shalt thou return.”

THE END.

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